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TEMPERATURE ANALYSIS HOWARD A. HANSON RESERVOIR, WASHINGTON

Mathematical Model Investigation

by

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The US Army Engineer District, Seattle, is presently evaluating the impacts of proposed additional water storage at Howard A. Hanson Reservoir in Washington State. This proposed modification will involve raising the existing pool approximately 40 ft. The investigation reported herein examined the impacts of raising the conservation pool on the reservoir thermal profiles and release temperatures for several study years. The mathematical model used in this study examined impacts of raising the pool with and without structural modification to the existing outlet works. Optimization procedures were used with the mathematical model to provide optimum number of and elevations for the additional ports. Results indicated that significant improvement in release temperatures for the raised pool could be achieved with a multilevel outlet structure as compared to the existing outlet works. The method for calculating the reliability index is given in Appendix A. Appendix B lists monthly temperature release statistics for existing conditions, and Appendix C lists the calculated average release temperatures for the reservoir.

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PREFACE

The numerical model investigation of the Howard A. Hanson Reservoir, reported herein, was conducted at the US Army Engineer Waterways Experiment Station (WES) at the request of the US Army Engineer District, Seattle.

The investigation was conducted during the period November 1985 to January 1987 in the Hydraulics Laboratory (HL), WES, under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL; J. L. Grace, Jr., former Chief, Hydraulic Structures Division (HSD); and G. A. Pickering, Chief, HSD; and under the direct supervision of Dr. R. E. Price, former Acting Chief, Reservoir Water Quality Branch (RWQB); and Mr. J. P. Holland, Chief, RWQB. This report, prepared by Mr. M. L. Schneider, RWQB, and Dr. Price with assistance from Mr. R. C. Berger, RWQB, was reviewed by Messrs. Holland and Pickering, and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

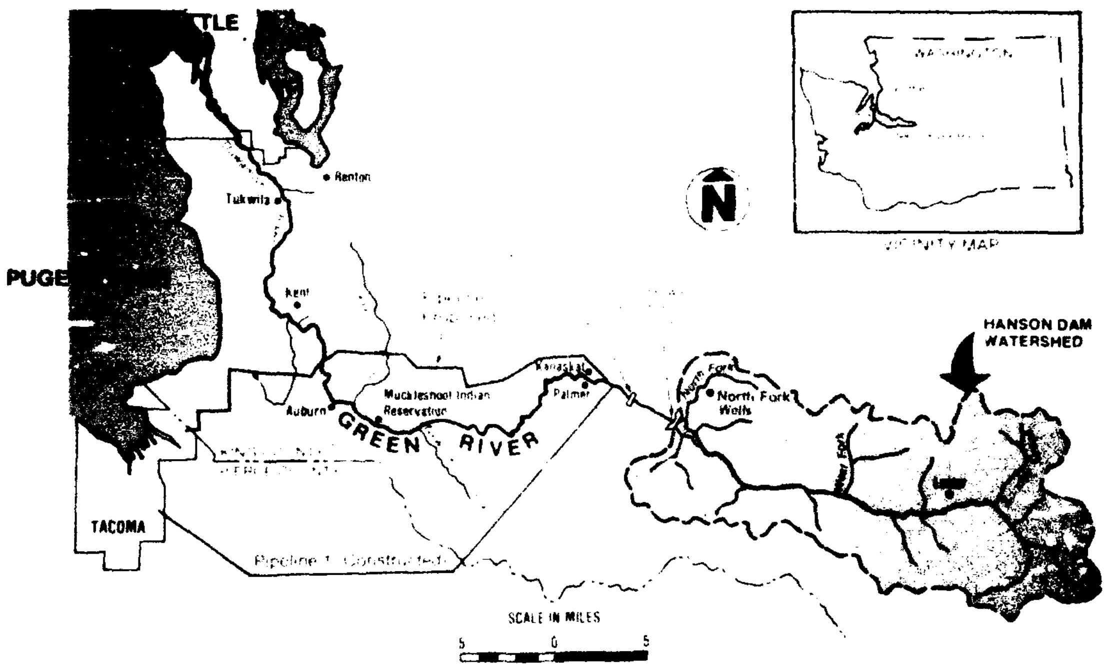
COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
inches	2.54	centimetres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
square miles	2.589998	square kilometres



HOWARD A. HANSON DAM

Figure 1. Location of Howard A. Hanson Reservoir

TEMPERATURE ANALYSIS

HOWARD A. HANSON RESERVOIR, WASHINGTON

Mathematical Model Investigation

PART I: INTRODUCTION

Purpose and Scope of Study

1. The Howard A. Hanson Project was authorized by Congress on 17 May 1950 to provide standard flood protection and minimum flow requirements for fisheries and other purposes in the Green River, WA. The US Army Engineer District, Seattle, is presently evaluating a proposed additional water storage modification to the project involving the raising of the maximum conservation pool by 40 ft.* Consequently, the present withdrawal structure may be inadequate to maintain preproject release temperatures (before the proposed increase in pool level). The purpose of this investigation is to examine the project release temperatures after the pool has been raised and, if these temperatures are significantly different from preproject conditions, provide the location and number of additional selective withdrawal intakes that will allow operation of the system to maintain downstream temperature objectives.

Project Description

2. Howard A. Hanson Dam is located 65 miles upstream from the mouth of the Green River and 35 miles east of the city of Tacoma in western Washington, as shown in Figure 1. The project drains 221 square miles of protected watershed in the Cascade Mountains. The earth- and rock-fill dam reaches a height of 235 ft above the streambed. The tainter gate controlled spillway is located in the right abutment of the dam with a maximum discharge capacity of 107,000 cfs at maximum project pool (el 1,220**). Normal releases are presently passed through a 19-ft horseshoe-shaped sluiceway controlled by

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* A table of factors for converting non-SI units of measurement to metric (SI) units is found on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

regulating tainter gates located at the bottom of the pool. The sluiceway releases about 22,000 cfs at maximum project pool. Low-flow releases are made through a 48-in. bypass intake located about 40 ft above the bottom of the pool. This outlet has a capacity of about 500 cfs at maximum conservation pool (el 1,141). The existing outlet tower is shown in Figure 2.

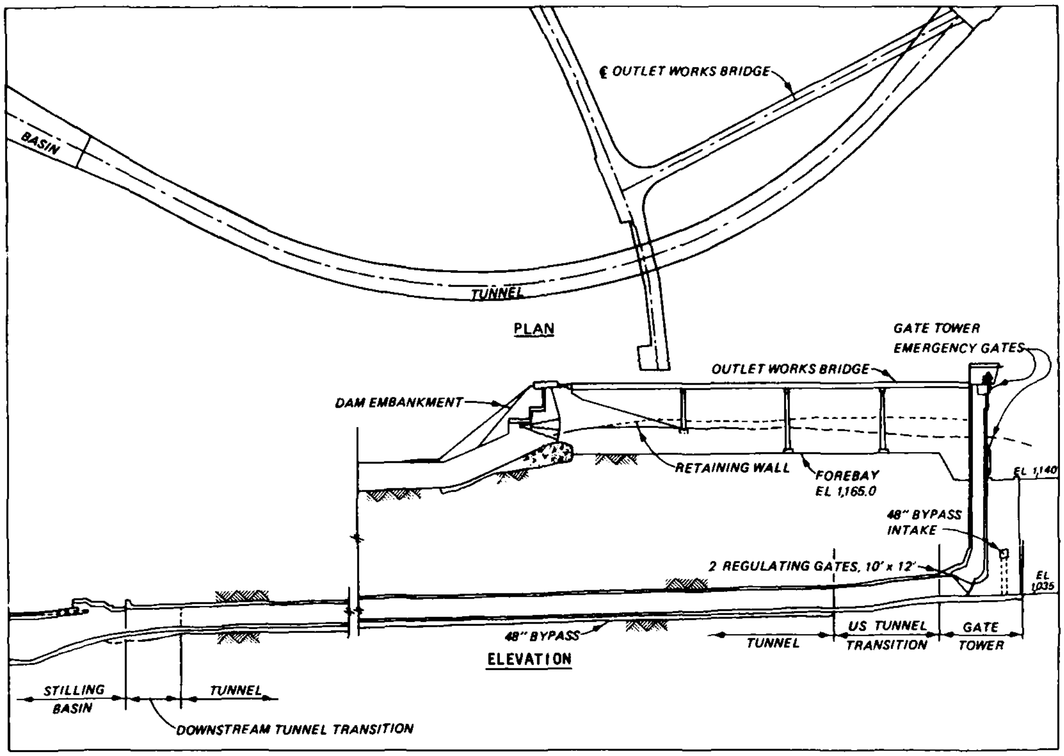

Figure 2. Howard A. Hanson outlet works

3. The reservoir operation rule curve is designed to prevent flooding downstream in the winter months and to augment low flows during the summer and fall for fishery enhancement. The reservoir is maintained at a depth of about 30 ft during the nonconservation period of the year (from 31 October through 31 March) except during unusually high rainfall conditions. The average yearly rainfall in the drainage basin is 89 in. with 75 percent of the precipitation occurring during this nonconservation season. Runoff hydrographs are characterized by frequent short-duration, sharply peaked events during the winter months followed by longer duration, smaller peaked hydrographs associated with snowmelt.

4. Beginning 1 April, the reservoir begins filling to a maximum conservation pool depth of el 1,141, as shown in Figure 3, while retaining water of

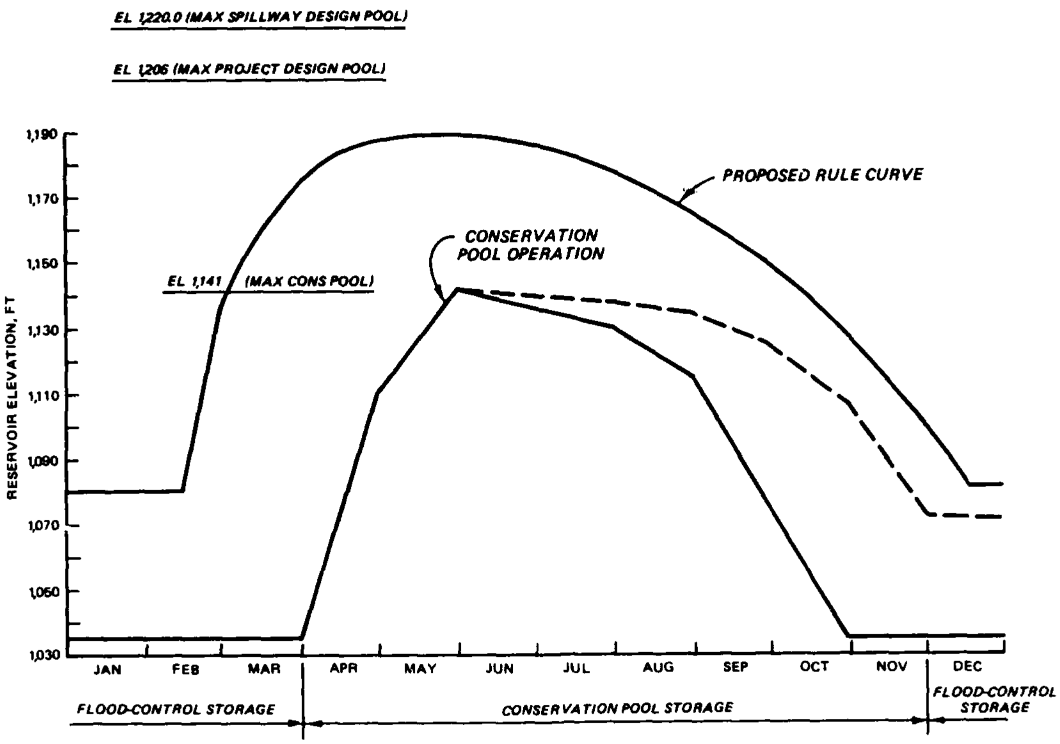

Figure 3. Existing and proposed rule curves

as low a turbidity as possible. Inflowing water impounded by Howard A. Hanson Reservoir is of good quality with low concentrations of dissolved minerals and nutrients. Turbidity levels in the tailwaters are the only parameter known to exceed water quality objectives at any time.

5. The reservoir impounds 25,650 acre-ft at full conservation pool with a surface area of 732 acres. During the summer-fall low-flow period, the pool is generally drawn down from minimum release requirements consisting of a 110-cfs discharge for fishery and conservation flows plus a 113-cfs discharge for water supply for the city of Tacoma. The city of Tacoma operates a concrete water supply diversion dam approximately 3.5 miles downstream of the project. No treatment except chlorination is generally required of this water supply for public use. However, during high-flow events, water in the Green River is sometimes too turbid for effective chlorination without dilution. At these times the city uses water from a well field to dilute the river water such that the combined water does not exceed 5 Nephelometric Turbidity Units (NTU's). Once the pool is established, the impoundment becomes thermally stratified in the late spring and early summer. Low-level releases provide for downstream temperatures slightly cooler than those which occur naturally

in the Green River during the conservation period.

6. The Green River is one of Washington State's primary habitats for salmon and steelhead. No anadromous fishery existed above the city of Tacoma's diversion structure prior to the construction of Howard A. Hanson Dam in 1961; the construction only further precluded the migration of fish upstream of the project. However, downstream passage is possible through the existing sluiceway, and fish have recently been planted above the dam. There is a strong commitment by both State and Federal resource agencies to preserve and enhance the anadromous fishery resources in the Green River Basin. The water resources demands in western Washington, however, are changing. The city of Tacoma has requested additional storage in Howard A. Hanson Reservoir for the purpose of water supply while the State of Washington would like to further augment Green River flows during the summer and late fall to enhance the fishery in the lower Green and Duwamish Rivers. These additional water supply demands would involve raising the maximum conservation pool 40 ft and impounding almost three times the existing conservation storage. This can be accomplished by beginning pooling operations on 1 March rather than 1 April and raising the pool to el 1,190. Over 500 additional acres of land would be inundated regularly by this proposed change. Specific concerns about raising the pool center on the impacts to the reservoir thermal stratification. With a deeper maximum conservation pool, a stronger stratification is possible. This stratification may alter release temperatures significantly and possibly impact the steelhead and salmon habitat downstream in the Green River. If this situation appears likely, a selective withdrawal structure may be needed to provide adequate control of release temperatures along with an operational plan to minimize depletion of desired thermal resources in the reservoir and to control release temperature fluctuations. Since fisheries upstream of Howard A. Hanson Dam are being developed, in-reservoir impacts may also be significant.

Approach

7. The approach taken in the investigation of proposed storage modifications to Howard A. Hanson Reservoir involved the application of a one-dimensional mathematical thermal reservoir model. The model was verified initially against historical data from 1982. Data collected during 1979 and

1983 were used for final verification. The impact of changing the storage allocation in the reservoir while still using the existing outlet tower was investigated by comparison of predicted release temperatures to release temperature objectives. Release temperature objectives providing an optimal environment for the varied downstream fisheries were specified by the Seattle District not to exceed 14.4° C throughout the year. Addition of selective withdrawal capability to the existing outlet was simulated to predict impacts on in-reservoir thermal profiles and release temperatures. Although other water quality characteristics may be affected by changes to the operating schedule, the influence on temperature was of primary concern in this study.

PART II: MATHEMATICAL METHODOLOGY

8. The downstream release and in-lake temperature characteristics for Howard A. Hanson Reservoir were modeled using a one-dimensional thermal simulation model. The model WESTEX used in this investigation was developed at the US Army Engineer Waterways Experiment Station (WES). The WESTEX model can be used for examining the balance of thermal energy imposed on a reservoir. This one-dimensional model includes computational methods for predicting dynamic changes in thermal content of a body of water through simulation of heat transfer at the air-water interface, heat advection due to inflows and outflows, and internal dispersion of thermal energy. The reservoir is conceptualized as a series of homogeneous layers stacked vertically. The time-history of thermal energy in each layer is determined through solving for conservation of mass and energy at each time increment subject to an equation of state regarding density. The boundary conditions at the water surface, inflow, and outflow regions are required to conduct these simulations. A numerical procedure for the withdrawal zone computation allows prediction of release temperature. Mathematical optimization routines have been added to this model enabling the systematic evaluation of optimal outlet configurations subject to specified release water quality objectives. A more detailed discussion of the WESTEX model may be found in Holland (1982).

Thermal Model Inputs

9. The WESTEX model required input data on the physical, meteorological, and hydrologic characteristics of Howard A. Hanson Reservoir. Hydrologic input included daily values for reservoir inflow and outflow volumes and inflow temperature. Meteorological data (air temperature, cloud cover, relative humidity, and wind speed) were used to compute surface heat exchange at the air-water interface. Physical characteristics required included the stage-storage relationship of the reservoir and the rating curves for the outlet structure.

Study Years

10. The years studied in this investigation were determined in

consultation with the Seattle District and were based on the inflow during the conservation period. Historical events of varying return periods were modeled to study reservoir thermal properties under a wide range of hydrometeorological conditions. The calendar year 1979 was chosen as representative of a low-flow year, 1972 as a high-flow year, and 1982 as an average-flow year. The year 1983 was added as an additional study year because of available field data. Simulations were run January through December, although the primary period of concern was during the conservation period after spring filling through the fall overturn.

Meteorological Data

11. Meteorological data required by the model were daily average values for wet and dry bulb temperatures, wind speed, and cloud cover. These data were available from the US Air Force Environmental Technical Applications Center (USAF-ETAC) at Scott Air Force Base, IL, for the Tacoma, WA, airport weather station, which is the nearest meteorological station to the Howard A. Hanson Dam. Meteorological data received from USAF-ETAC were averaged on a daily basis. Equilibrium temperatures, surface heat exchange coefficients, and daily average solar radiation quantities for the years of study were computed using the HEATEX program (Eiker 1977).

Hydrology

12. Hydrologic data provided by the Seattle District consisted of daily discharge from the project (Figure 4) and pool level fluctuations from which the average daily inflow (Figure 5) was computed. The existing operating schedule for the project and the proposed rule curve were also provided.

13. Historic inflow temperatures were available for 1970 to 1973 and 1985 at Humphrey, WA, on the Green River. Since inflow temperatures for several of the study years were not available, a multiple regression technique was used to predict inflow temperature.

14. The regression analysis (Statistical Analysis System 1985) used water temperature of the inflow as the dependent variable. The independent variables included flow, logarithm of flow, air temperature, and logarithm of air temperature. This first-order model assumed that the parameters and the

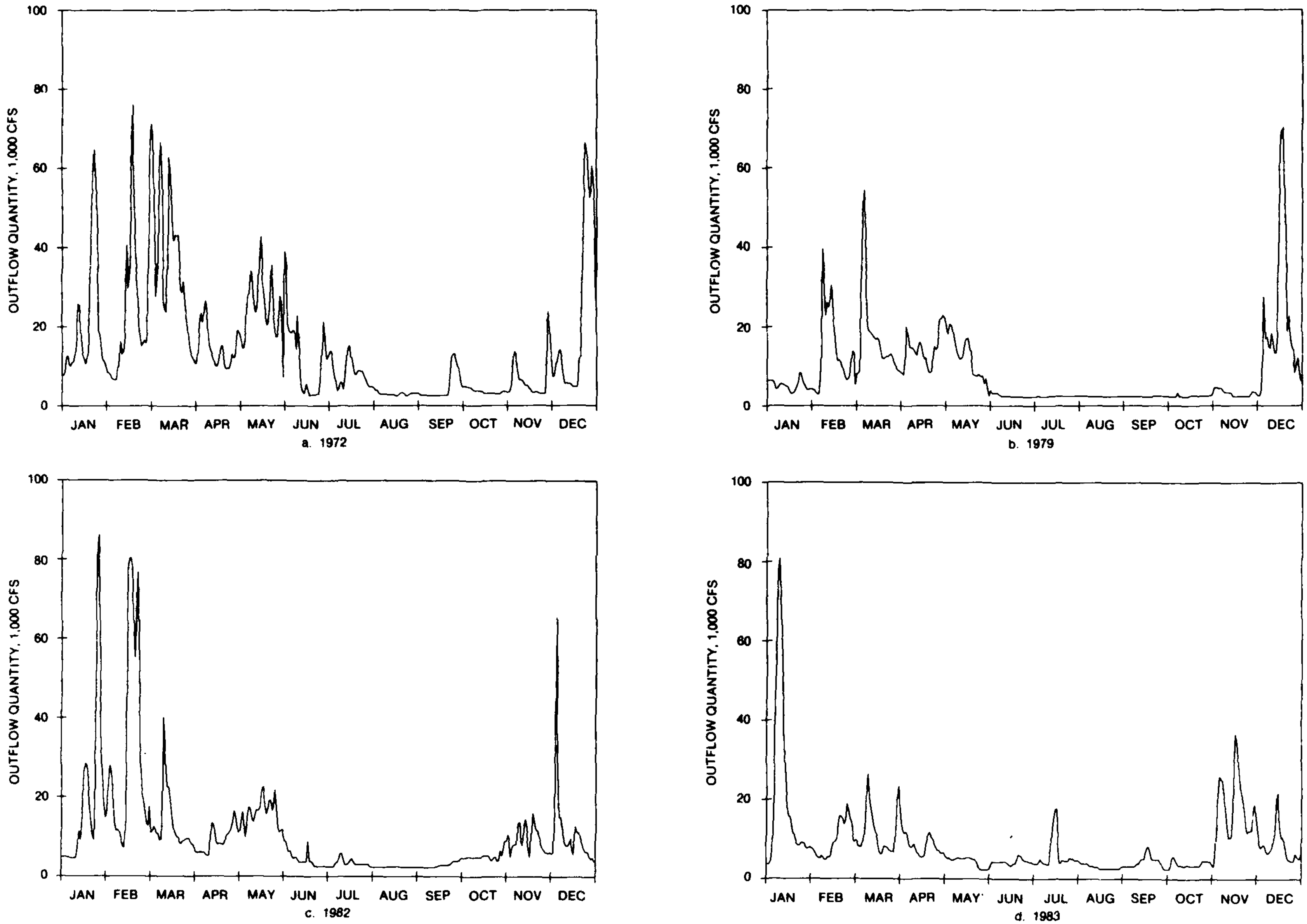

Figure 4. Daily outflow quantity

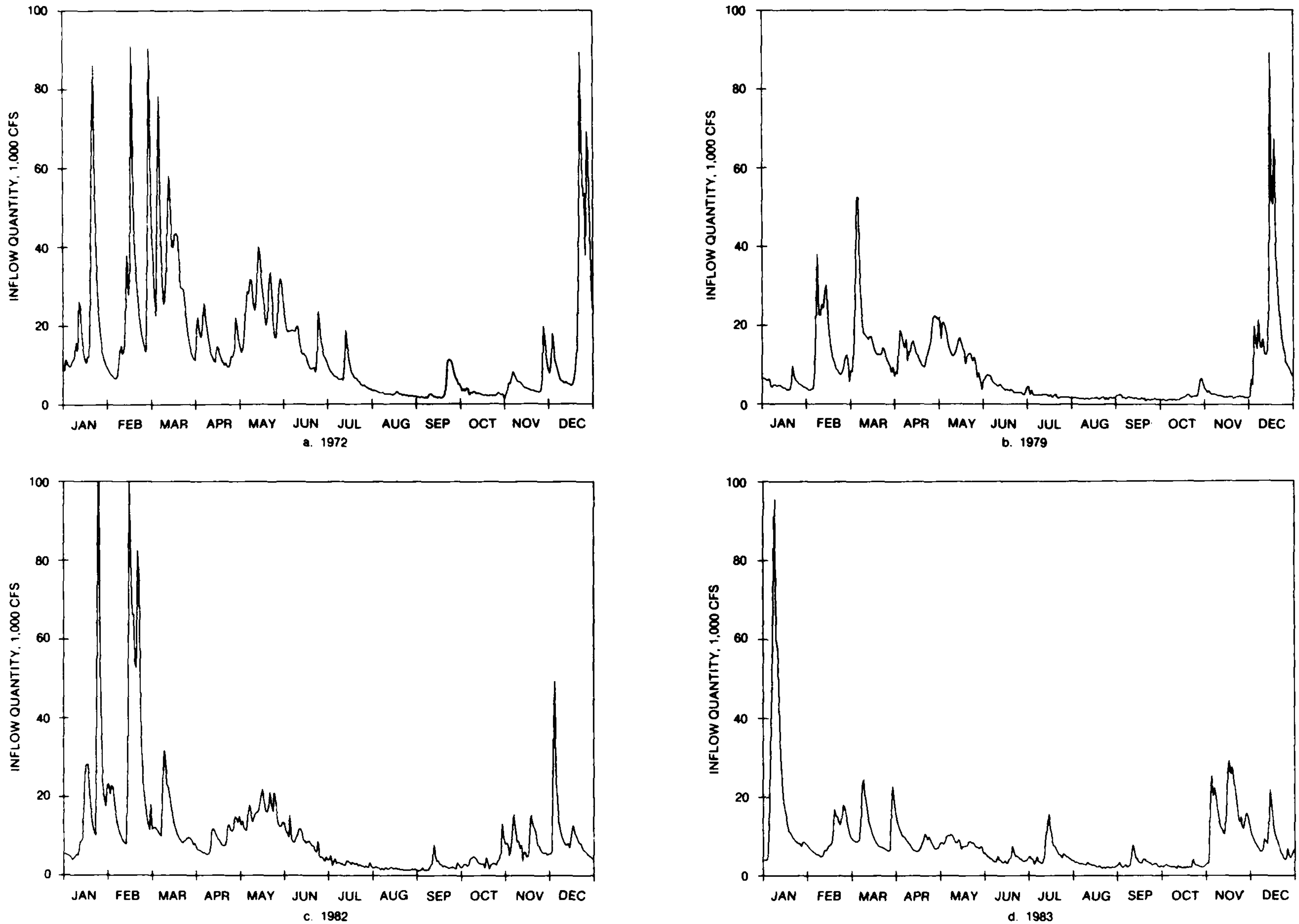

Figure 5. Inflow quantity to reservoir

independent variables were linearly related. The general form of the model tested was

$$Y_i = \beta_o + \beta_i\, xi_1 + \beta_2\, xi_2 + \varepsilon_i \qquad (1)$$

where

Y_i = stream water temperature for day i

$\beta_o, \beta_1, \beta_2$ = parameter or coefficients for the model

xi_1, xi_2 = independent variables (i.e., air temperatures, flow, logarithm of flow, logarithm of air temperature)

ε_i = error term which is assumed to be zero

The regression analysis consisted of 672 observations over a 4-year period. A summary of the regression analysis follows:

Step	Parameter Entered	Partial R^2	R^2	Total Squared Error
1	Air temperature	0.74	0.74	865.8
2	Logarithm of flow	0.14	0.88	36.4
3	Flow	0.01	0.89	3.1

Because the addition of flow in the third step improved the coefficient of determination R^2 by only 0.01, it was left out of the final equation. Therefore the resulting equation describing inflow temperature was

$$\text{Inflow temperature}_i = (0.297 \times \text{air temperature}_i) - (1.932 \times \text{logarithm flow}_i) + 5.726 \qquad (2)$$

where i is the day of the year. Inflow temperatures computed for 1972, 1979, 1982, and 1983 are presented in Figure 6.

Release Temperature Data

15. Daily release temperature data from the dam were monitored at the city of Tacoma's water supply intake located approximately 3.5 miles downstream from the project. These data proved to be an unreliable measure of release temperatures from the project through a comparison with tailrace temperatures collected in the summer of 1985. Therefore, with the exception

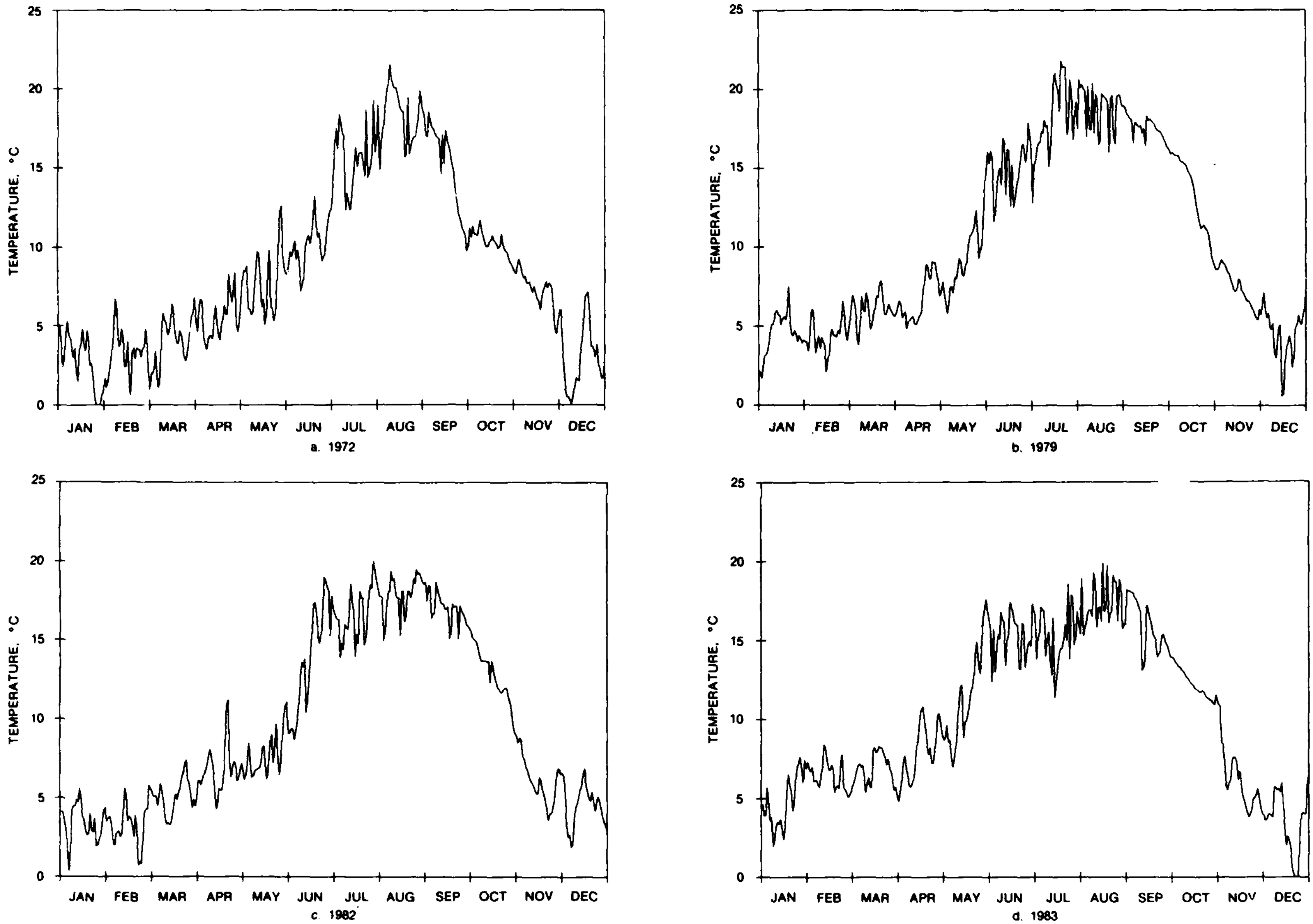

Figure 6. Inflow temperature to reservoir

of 1985, release temperature data were not available for measuring the performance of the numerical model.

Physical Characteristics

16. The physical characteristics of the xisting outlet at Howard A. Hanson Reservoir were required data for simulation of historical events. The port elevations, dimensions, and rating curves were obtained from project records. Operating conditions for given historic events were also required during model adjustment and verification. A third-order polynomial was fitted to the rating curve of the existing water quality port to calculate the flow capacity of this port for a given submergence. This calculation was required because of the significant pool fluctuations that occurred throughout the year.

17. The area-capacity data for Howard A. Hanson Reservoir as furnished by the Seattle District indicated the lake storage curve is typical of mountainous terrain. Only 7 percent of the storage at maximum conservation pool occurred at or below the elevation of the low-flow outlet, indicating little storage in the lower levels of the reservoir.

Model Verification

18. The WESTEX model requires determination of coefficients characterizing certain reservoir processes. The hydrodynamic processes representing entrainment of inflows and internal mixing resulting from circulation within the reservoir are approximated through the application of mixing coefficients α_1 and α_2, respectively. The distribution of thermal energy absorbed into the pool is governed by the surface absorption coefficient β (which provides the percentage of incoming shortwave radiation absorbed in the surface layer) and the light extinction coefficient λ. These model coefficients were modified until modeled conditions most nearly approximated field observations for the year 1982. The resultant model coefficients were as follows: $\alpha_1 = 0.50$, $\alpha_2 = 1.00$, $\beta = 0.85$, and $\lambda = 0.08$.

19. The 1982 simulation was initiated on 1 January with an initial uniform temperature of 4° C. Conditions during the nonconservation period of the year were nearly isothermal with an average depth of only 30 ft. Storm

events during this period resulted in significant fluctuation in the pool level. Storage was quickly released after these events to provide additional flood-control benefits. Generally, spring filling began on the receding side of the snowmelt hydrograph in May to minimize total lake turbidity. Once the pool was established, thermal stratification developed rapidly. The maximum stratification occurred during the early summer when cool inflows were still available. As the summer progressed, surface temperatures ranged up to 20° C. Release water temperatures were significantly cooler than objective temperatures in the spring and early summer. Release water temperatures increased linearly from 6° C at the beginning of April to 14° C by the end of June. Temperatures exceeding 14° C were released throughout most of the summer and early fall. At the beginning of September, lake overturn began with the remaining stratification quickly dissipating. The low-flow outlet was operated until the pool was drawn down near the end of November. Plots of these observed profiles along with predicted profiles for 1982 are shown in Figure 7. Modeled and observed results were generally within 1° C throughout the simulation period. The reliability index (RI), which is a general measure of the degree of fit of a predicted profile to an observed profile, for all profiles in 1982 was 1.1342. An RI of 1.00 indicates a perfect fit of predicted to observed data, and as the RI increases, the degree of agreement diverges. A more detailed discussion of this computation appears in Appendix A. The RI improved as the meteorological conditions become the significant source of heat flux into the reservoir. This improvement corresponded with the establishment of the pool during the conservation period. Prior to this period, calculated temperature properties were only as good as the simulated inflow temperatures.

20. The release temperatures from the project were highly variable during the nonconservation portion of the year and reflected the rapidly changing hydrological and meteorological weather conditions. Spring filling initiated the stabilization of release temperatures with a near-linear increase in project release temperatures. Only large hydrologic events significantly influenced release temperature during this period. The releases were dominated primarily by the meteorological warming of the reservoir. Since the releases came from the hypolimnion, tailwater temperatures were consistently cooler than the naturally occurring stream temperatures during the spring and early

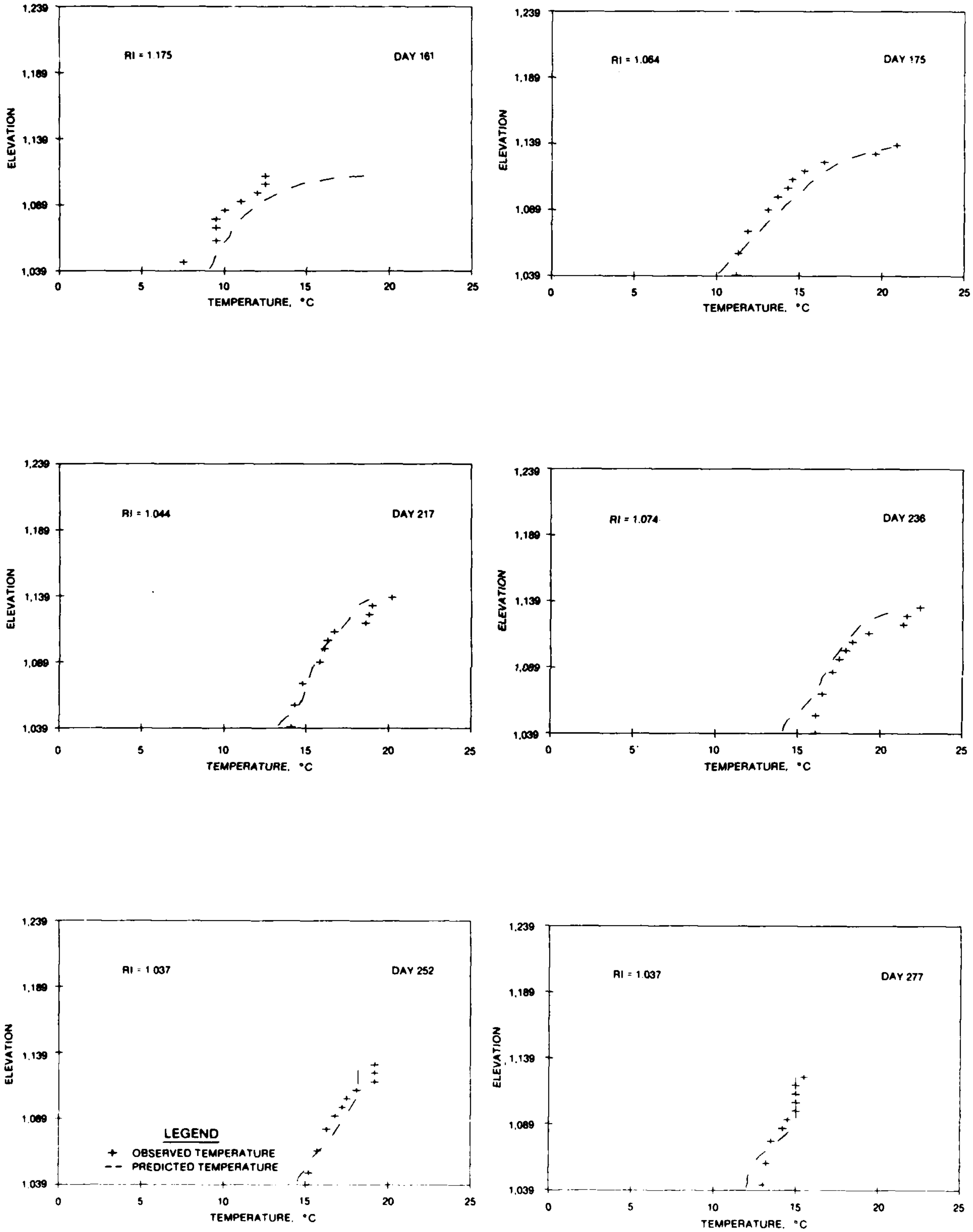

Figure 7. Predicted and observed temperature profiles for Howard A. Hanson Reservoir for 1982

summer. In the late summer and fall, release temperatures exceeded ambient stream temperatures.

Final Model Verification

21. The mathematical model was verified through comparison of predicted and observed thermal conditions for the years 1979 and 1983 (Figures 8 and 9, respectively) using model coefficients determined during the initial adjustment phase. The degree of agreement between observed and simulated thermal properties was similar to the results for 1982. The composite RI's for all of the 1979 and 1983 temperature profiles were 1.0408 and 1.0673, respectively. During the pooled conservation period, the predicted and observed temperature profiles deviated by no more than 1° C. This degree of agreement between modeled and observed temperature characteristics remained throughout the stratified period and into the fall overturn for both verification years.

Existing Reservoir Conditions

22. The current operational schedule for Howard A. Hanson Reservoir as discussed in Part I calls for release of all inflow from January through March. Beginning the first of April, the pool is raised until the maximum conservation pool is reached (el 1,141). However, in the years under study, pooled conditions were not initiated until late May or early June. The inflows (Figure 5) during April were still sufficiently large to require operation of the flood-control gate. In 1972, the highest flow year under investigation, inflows during May frequently exceeded 30,000 cfs. The peak inflow for the 4 years approached 100,000 cfs and occurred between January and March of each year. This inflow pattern created the fluctuating stages observed during the nonconservation period. Once the conservation period was initiated, the pool filled rapidly, usually in less than 2 weeks. In 1983, low flows during May extended the filling period to almost 4 weeks.

23. Thermal stratification began with conservation pool operation as illustrated by the annual temperature contours shown in Figure 10. A rapid warming of the reservoir was indicated by the nearly vertical temperature contours in late May through July. During midsummer to late summer, a relatively stable temperature profile developed, followed by rapid cooling and overturn

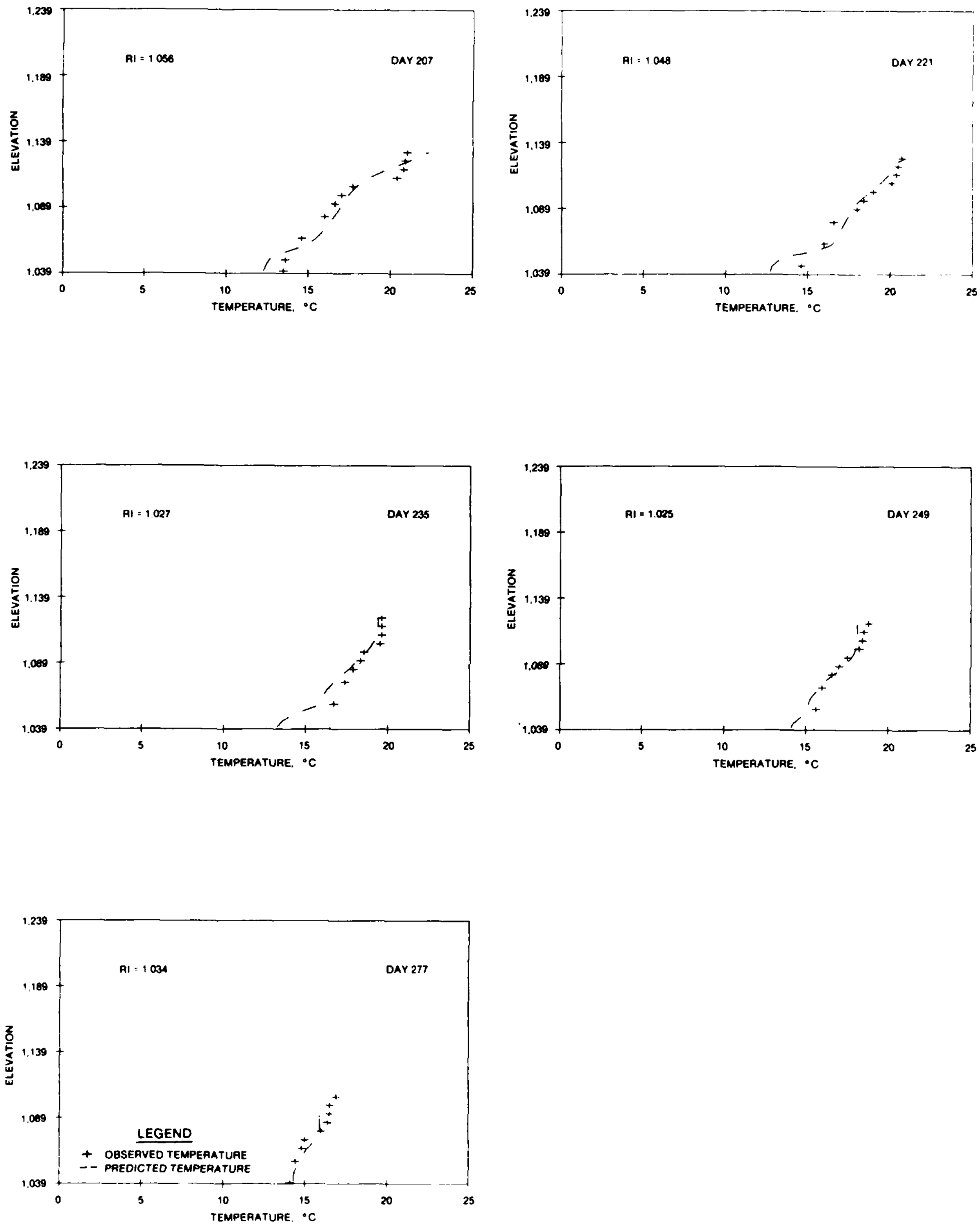

Figure 8. Predicted and observed temperature profiles for 1979

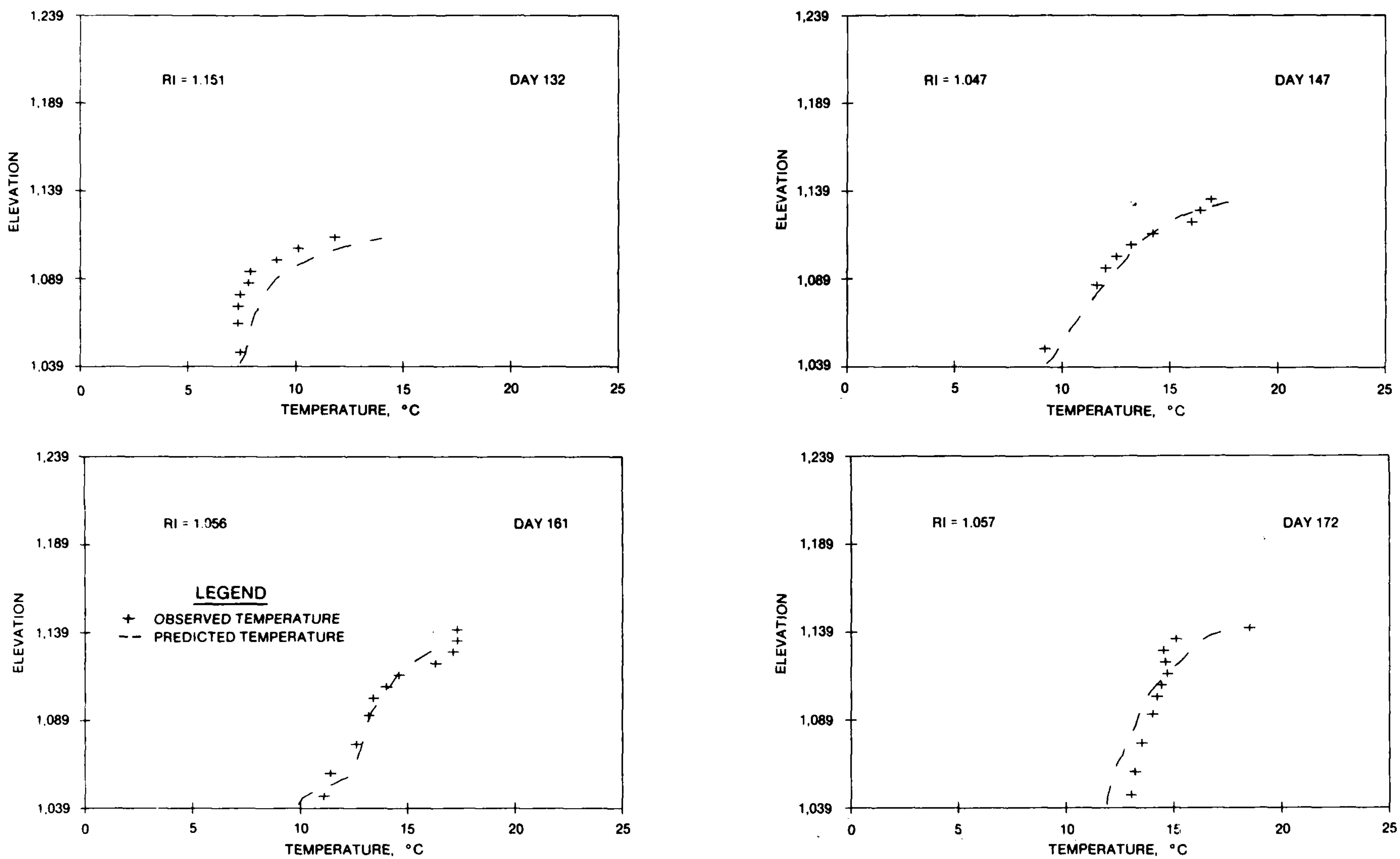

Figure 9. Predicted and observed temperature profiles for 1983 (Continued)

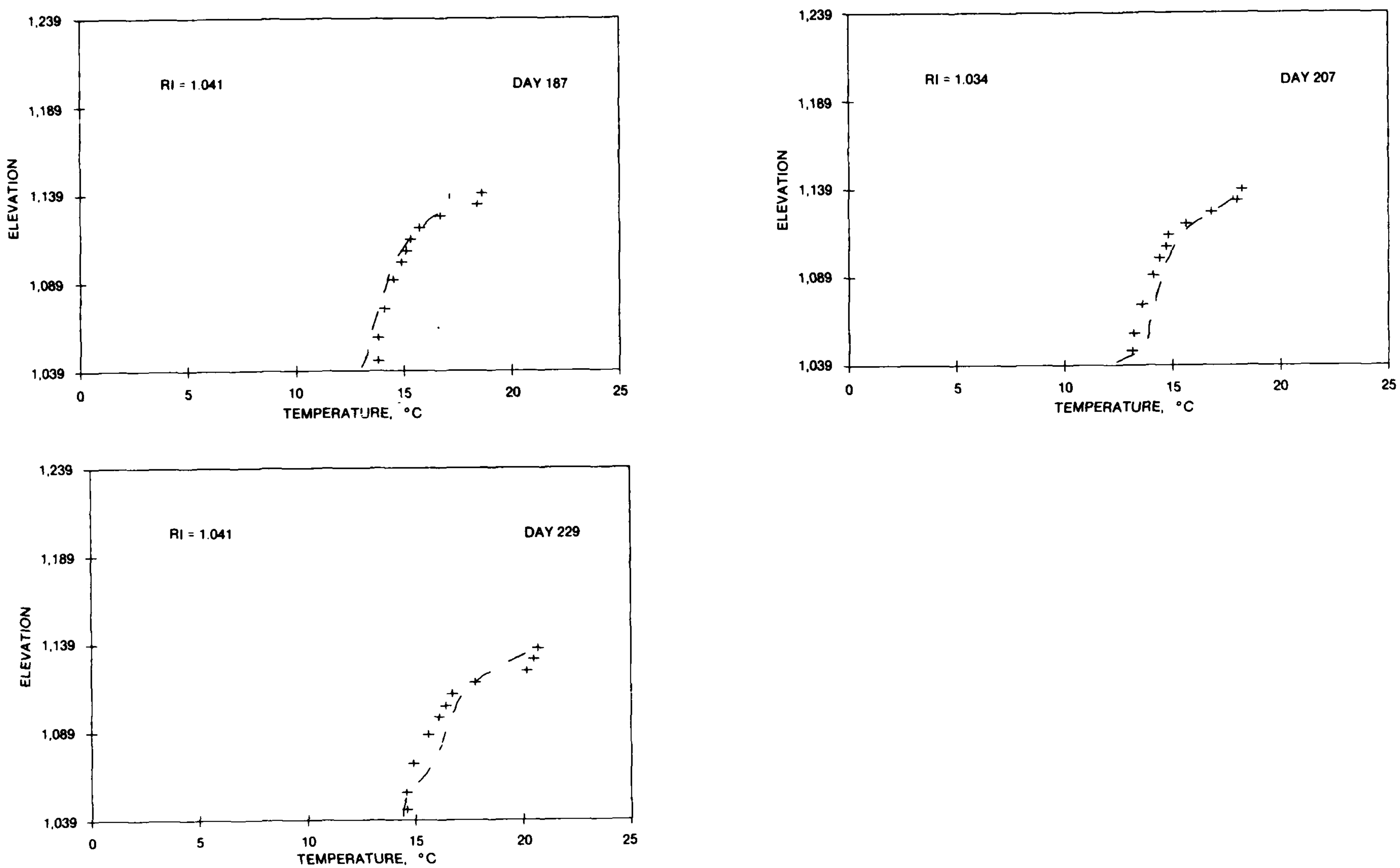

Figure 9. (Concluded)

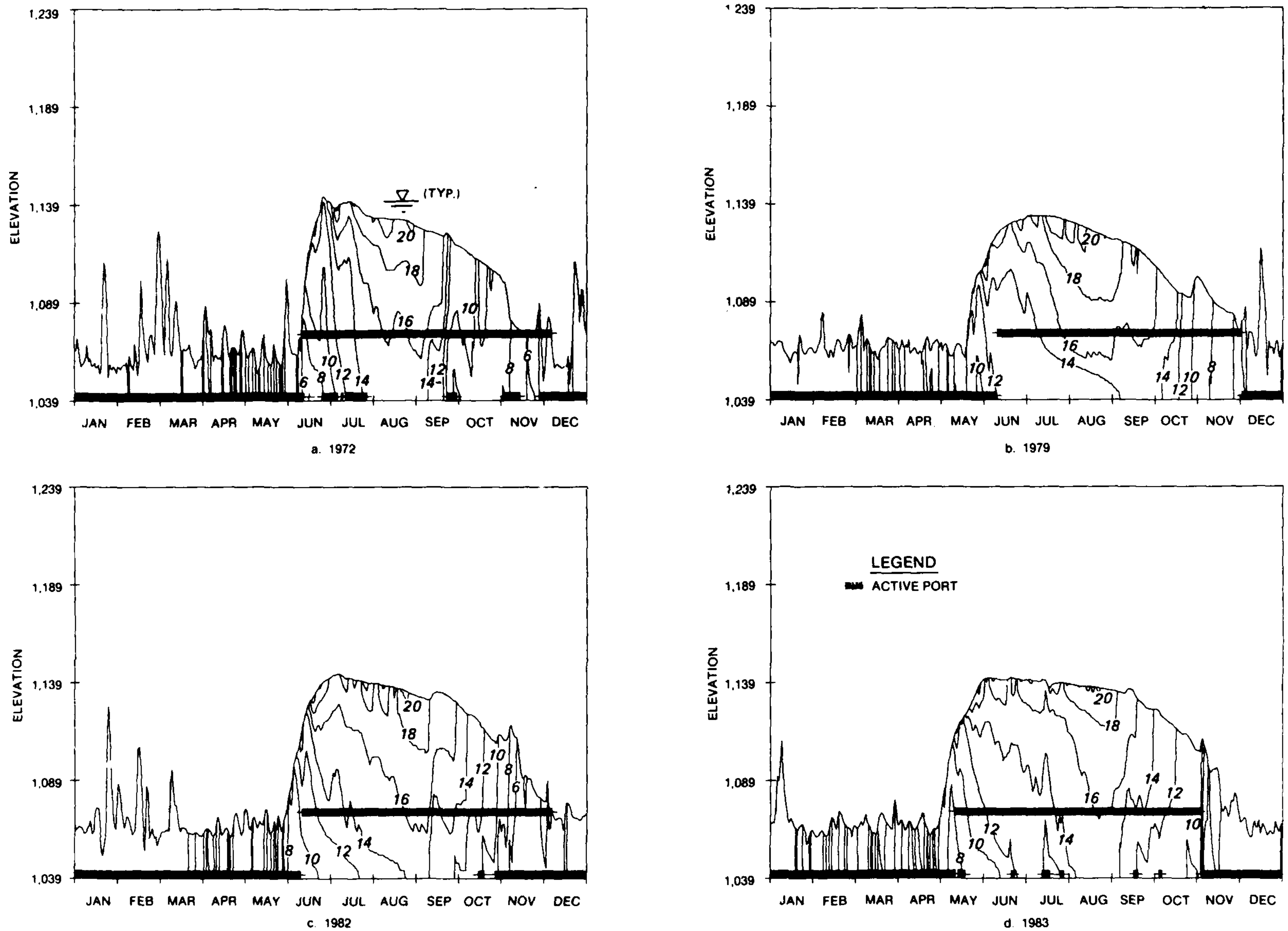

Figure 10. Seasonal temperature contours and port operation

in the fall. Surface temperatures fluctuated much more rapidly than hypolimnetic temperatures due to the insulation characteristics of the water body. Although the degree of stratification was relatively weak, as indicated by the lack of a well-defined thermocline, the temperature difference between the surface and the bottom reached 15° C. Surface water temperatures equal to or exceeding the maximum objective release temperature of 14° C generally first appeared from mid-May to early June. The 14° C water appeared at the level of the low-flow outlet during the month of July followed by a period of approximately a month where the entire pool was warmer than 14° C.

24. During the nonconservation periods, the pool was shallow, release rates were high, and there was little stratification, thereby causing water to be released from the entire profile. As a result, the release temperatures fluctuated considerably in response to local weather trends. During the conservation period, the withdrawal zone developed in the lower two-thirds of the pool as shown in Figure 11. Epilimnetic waters remained outside the withdrawal zone despite the lack of a strong thermocline because of small release rates during this period. The historic release water temperature characteristics as simulated by the WESTEX model exceeded the designated objective temperature ceiling of 14.4° C for all study years. Releases during August consistently exceeded 14.4° C with maximum daily release temperatures ranging from 17.1° to 16.2° C for 1979 and 1983, respectively. The worst-case conditions occurred during the study year 1979 when the average daily release temperature exceeded 14.4° C for 97 days during the months of July through October. For the remaining three study years, 1972, 1982, and 1983, daily release temperatures exceeding 14.4° C occurred for 63, 61, and 44 days, respectively. The daily release temperatures for existing conditions are illustrated in Figure 12. This figure shows the variability of release temperatures decreasing as the pooled conditions develop. Monthly temperature release statistics for existing conditions are tabulated by study year in Table B1.

25. The stability of stratification index is a measure of the degree of stratification in a reservoir. Stability of stratification can be defined as the condition which occurs during the summer stratification period in which there is a certain degree of stability or resistance to mixing of the epilimnion with the hypolimnion. It is measured by computing the amount of work required to mix the lake to a uniform density neglecting heat losses or gains through the system boundaries. By definition, a uniform temperature profile

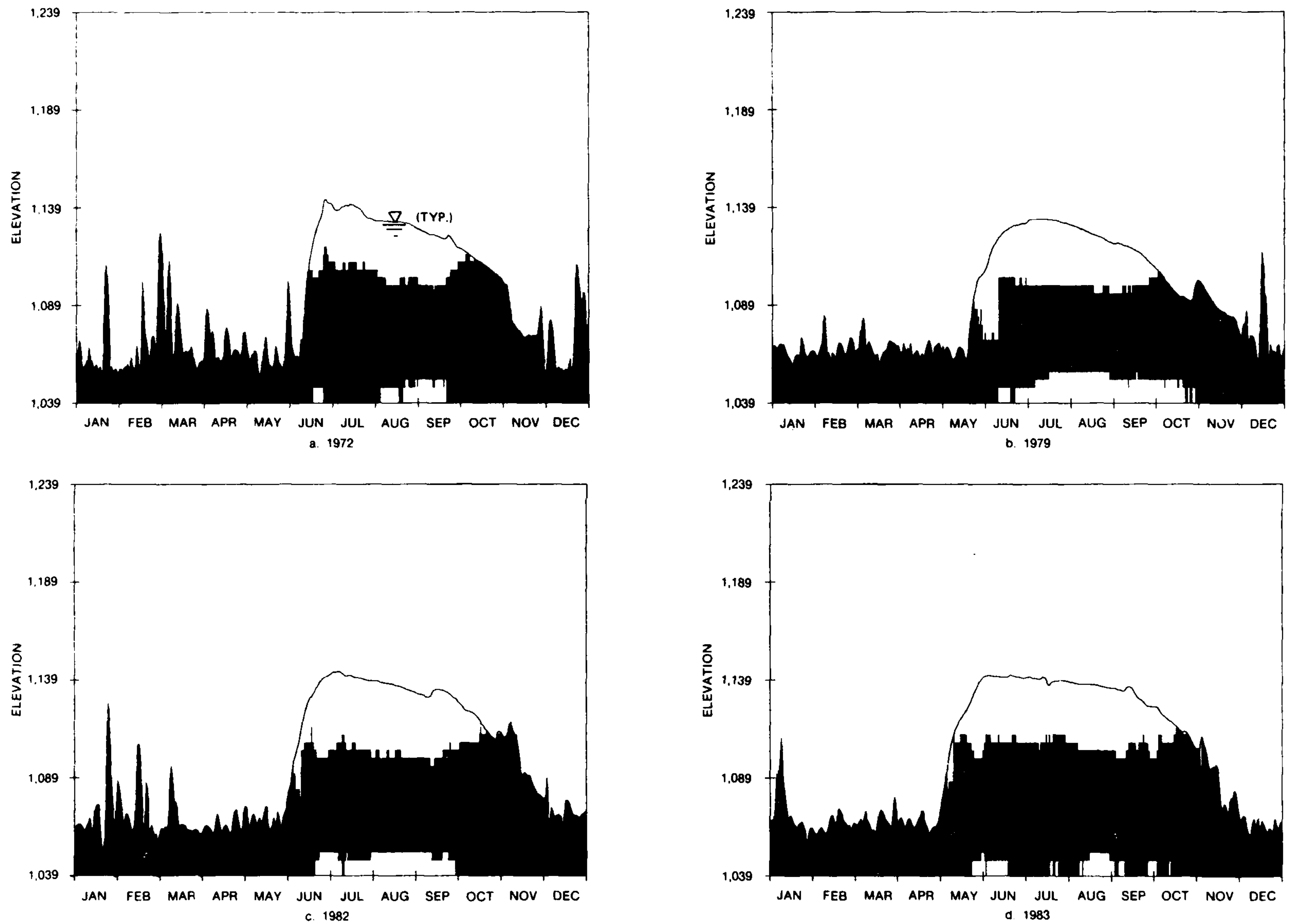

Figure 11. Withdrawal limits. Band indicates limits of withdrawal

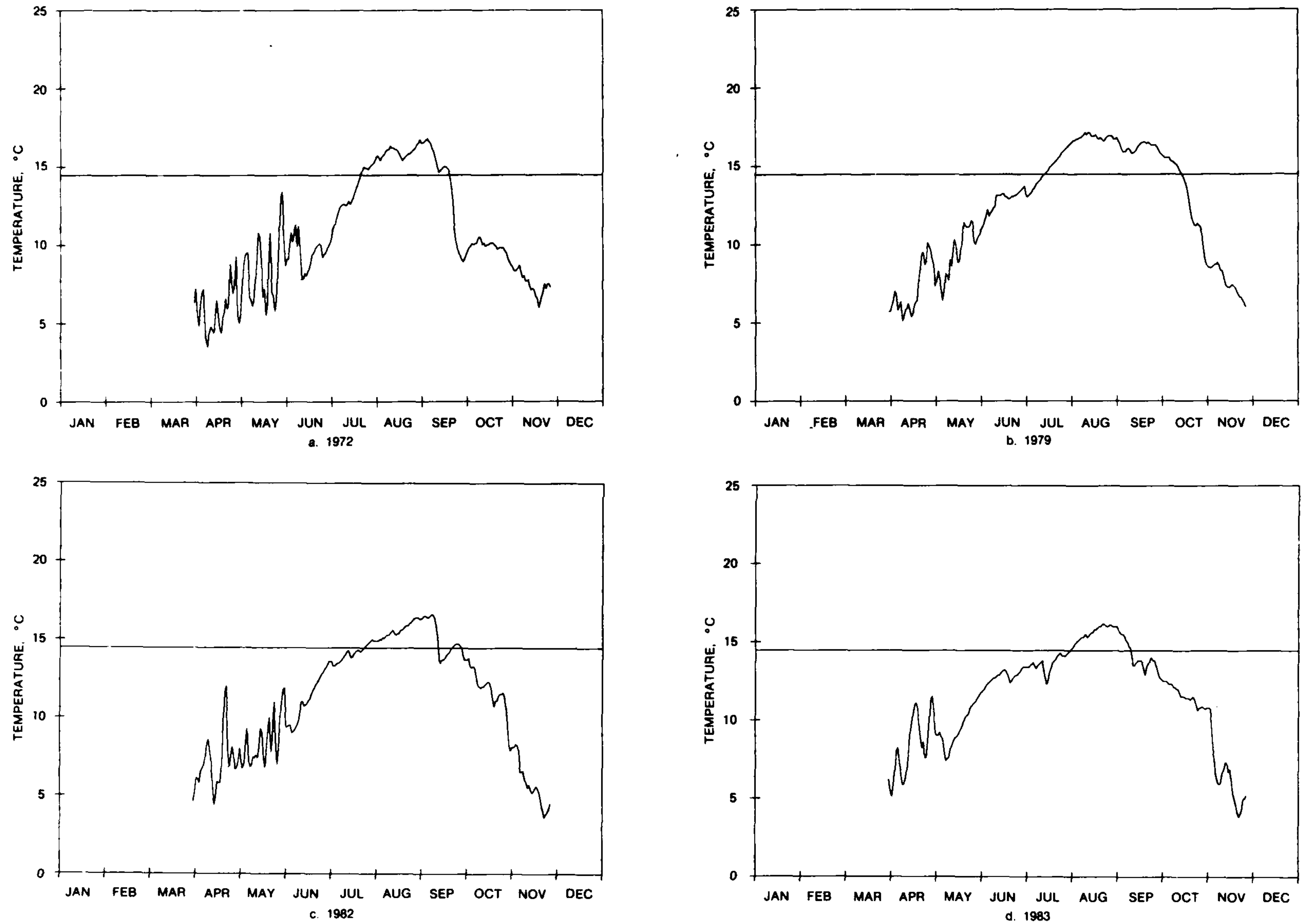

Figure 12. Daily average release temperatures

has a stability of stratification index equal to 0. Thus the larger the index, the stronger the stratification. The method of computing stability is after Idso (1973):

$$S = \frac{1}{A_o} \int_{z_o}^{z_m} (\rho_z - \bar{\rho}) (A_z) (z - z_{\bar{\rho}}) \, dz \qquad (3)$$

where

A_o = surface area, square centimetres

z_m = maximum depth, centimetres

z_o = surface or zero depth, centimetres

ρ_z = density at z depth, grams per cubic centimetre

$\bar{\rho}$ = mean density resulting from total lake mixing, grams per cubic centimetre

A_z = Area at z depth, centimetres

z = depth from free surface, centimetres

$z_{\bar{\rho}}$ = depth where the mean density ρ exists prior to mixing

dz = integration variable, centimetres

Stratification began in May or June for the existing pool conditions with the exception of 1979 where hydrologic conditions delayed the peak stability until late July. The general progression of the stability plot (i.e., initial peak followed by a gradual decline) indicated that the thermocline was weak. In general terms, stability will increase as a thermocline moves down in the water column but will decrease as it passes below the center of gravity of the pool (Rutner 1963). Because the stratification was weak in Howard A. Hanson Reservoir, stability peaked once the full pool was reached and declined with the stage of the reservoir. This also suggests the strong influence of the operation of the project on the thermal characteristics of the pool (Figure 13).

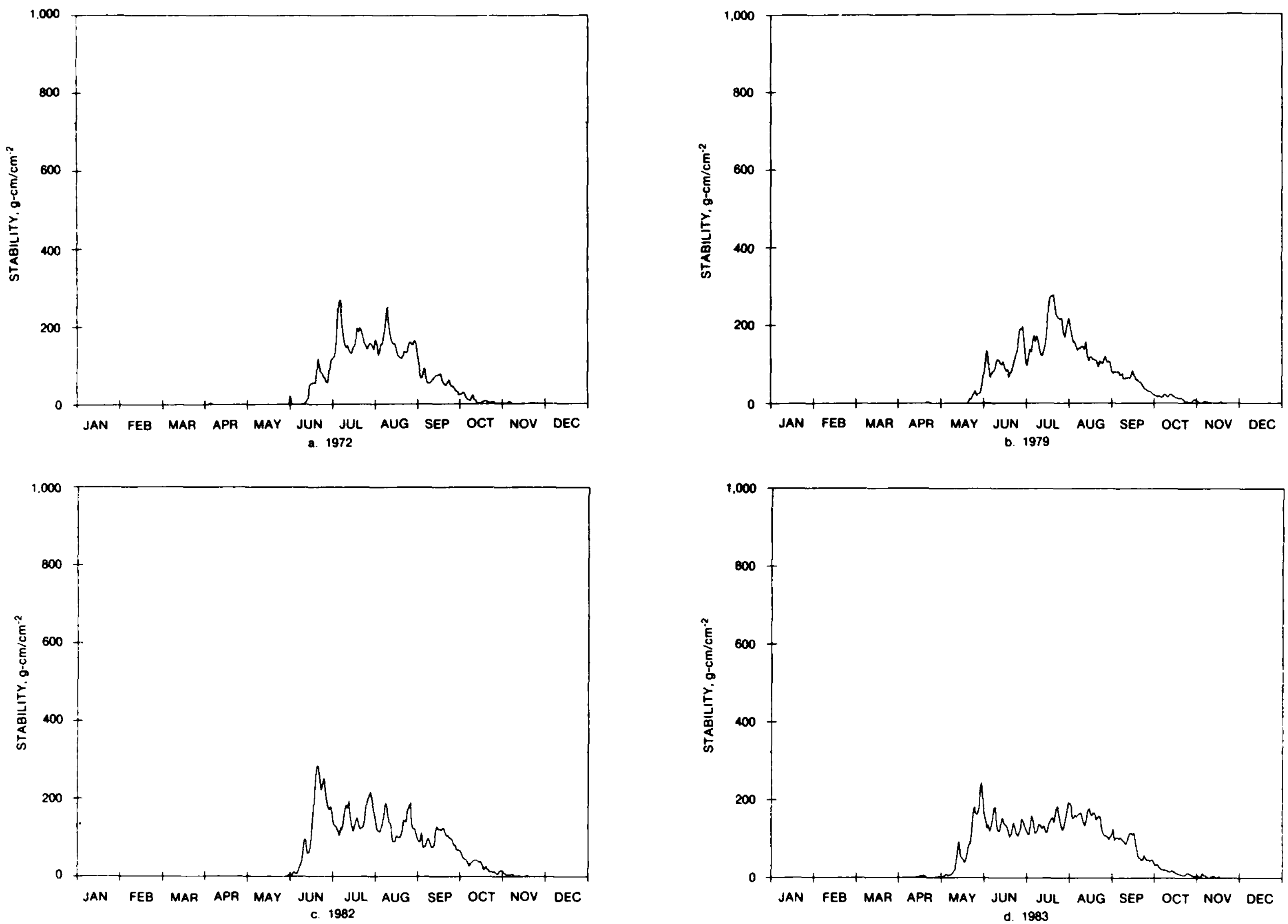

Figure 13. Stability of stratification

PART III: RESULTS OF PROPOSED STORAGE REALLOCATION

Existing Structure with Raised Pool

26. The proposed operational changes enabling additional storage at Howard A. Hanson Reservoir were incorporated into the release schedule for each of the study years subject to the hydraulic constraints of the existing outlet configuration. The proposed rule curve specifies spring storage to begin the first of March and to reach a maximum conservation pool of el 1,189. The minimum low-flow release from the project is proposed to almost double to 412 cfs: 212 cfs for Tacoma water supply and 200 cfs for low-flow augmentation for fisheries enhancement. The proposed rule curve is shown in Figure 3.

27. The operational changes dictated by the proposed rule curve were simulated for each of the study years. Daily operational releases were determined to meet the rule curve subject to constraints of minimum release. The low-flow port was operated from early June through November (the current operating procedure) although releases through this outlet could be initiated earlier in the year. The maximum release through the port was increased due to the greater submergence of this outlet. Compared with existing conditions, the raised pool scenario required operation of both sluiceway and ports for longer periods in the spring and fall to meet scheduled releases (Figure 14).

28. The in-reservoir thermal characteristics resulting from the raised pool scenario were slightly different from existing conditions. The surface water temperatures started to warm earlier in the year because of longer residence times as well as increased surface area. The comparison of predicted thermal profiles in the raised pool with observed profiles from the existing pool indicated a warmer profile earlier in the stratification period and the retention of more thermal energy with the raised pool. However, by midsummer to late summer, the shape of the predicted raised pool temperature profile was analogous to the profile observed in the existing reservoir. The maximum hypolimnetic temperature generally occurred several weeks later in the fall for the raised pool because the hypolimnetic storage was much greater than that of the unmodified pool. The raised pool did not become isothermal until late November as compared to early November for the existing pool.

29. The stratification for the raised pool was more stable than that of the existing pool conditions (Figure 15). Even though the temperature

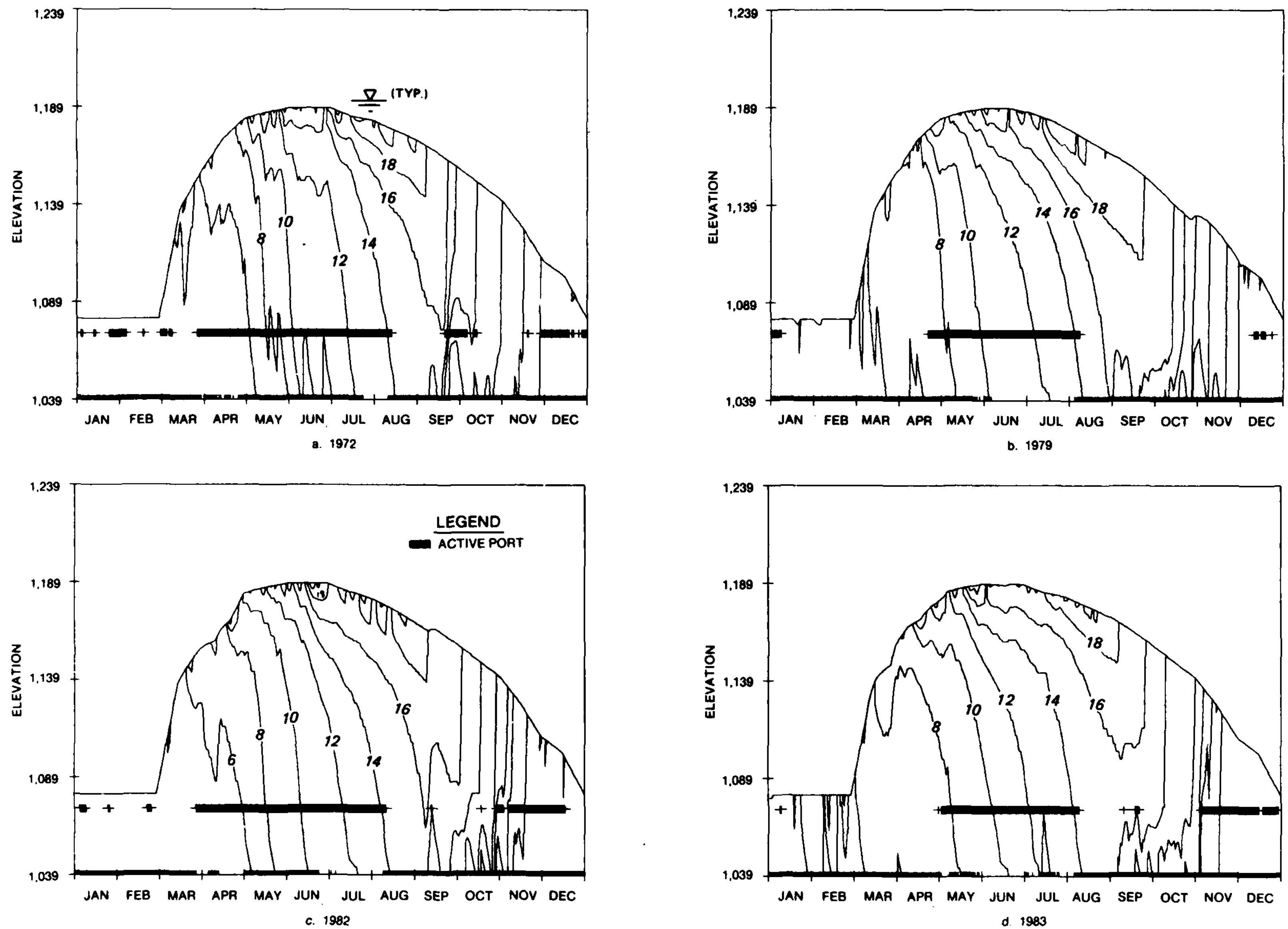

Figure 14. Seasonal temperature contours with the raised pool and existing outlet

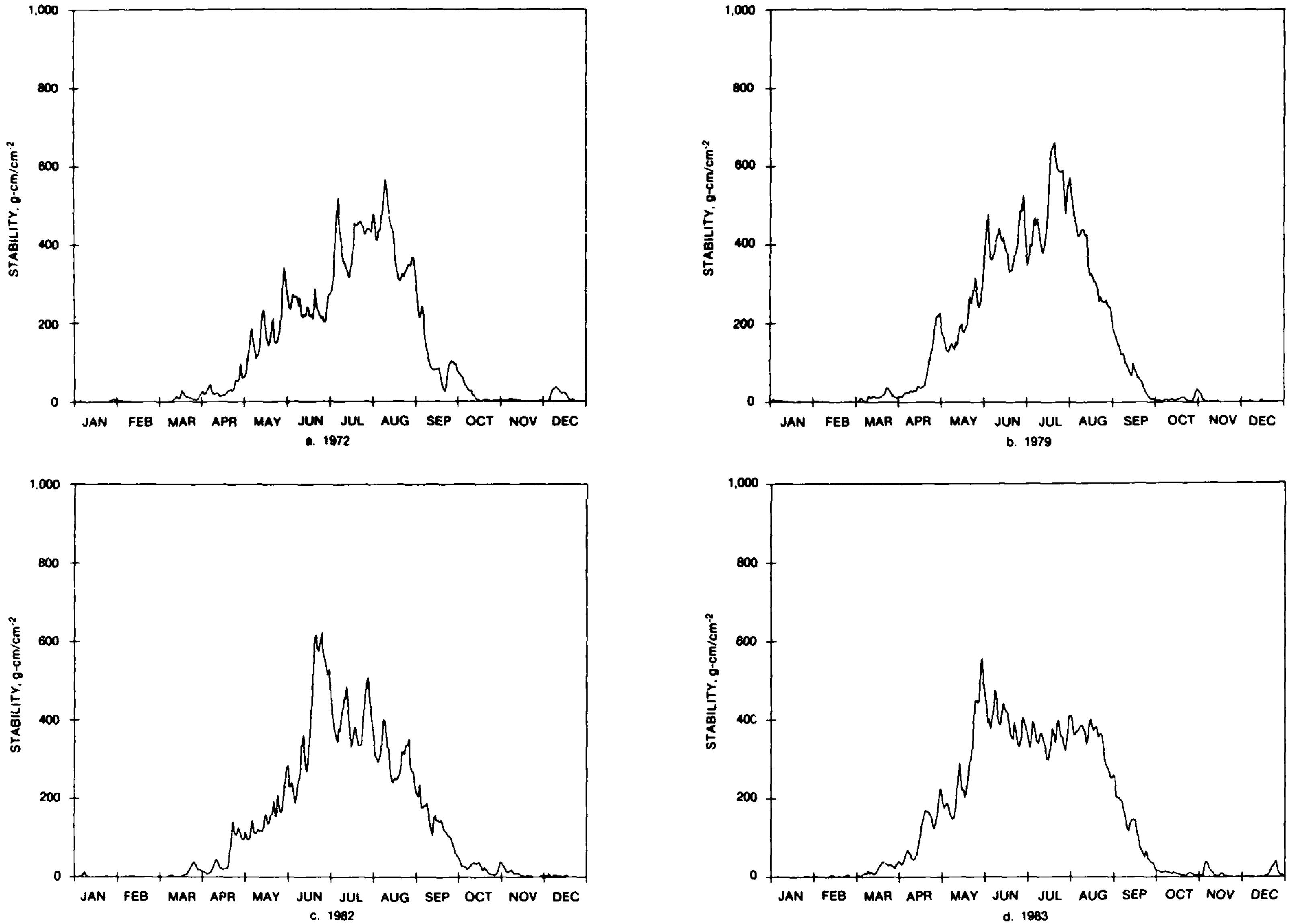

Figure 15. Stability of stratification for the raised pool

contours in the epilimnion were not altered significantly by the raised pool, the volumetric availability of temperature resources was significantly changed. The storage volume in the top 10 ft of the raised conservation pool was two times greater than that of the same region of the existing pool. The shape of the stability of stratification plot for each year was similar to that of the existing pool (Figure 13) with one exception. The maximum peak for 1972 was not reached until August in the raised pool scenario (Figure 15), while in the existing conditions the maximum stability was reached in July (Figure 13). This difference may be due to a relatively large cool inflow volume during June and July of 1972.

30. The impacts of the raised pool on release temperatures were most significant during the spring and early summer (Figure 16). The day-to-day release temperature fluctuations were not as prevalent under the proposed conditions because of the temperature stability of the deeper pool. Release temperatures from April through August were several degrees cooler than the existing conditions for all study years, as shown in the following tabulation, which lists the projected change in monthly release temperatures:

	Projected Change, °C							
Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1972	-0.8	-0.7	1.0	-1.1	-1.5	0.2	1.1	0.6
1979	-0.8	-0.5	-1.9	-2.1	-1.7	0.3	1.0	1.0
1982	-1.7	-0.6	-0.9	-1.7	-1.1	0.0	0.8	0.6
1983	-1.7	-1.1	-2.2	-1.0	-1.0	0.3	0.8	0.6

The maximum release temperature can be expected to be lowered up to 1° C by employing the proposed operating schedule as compared with existing conditions. The length of time release temperatures exceed 14.4° C will also be reduced 2 to 4 weeks. In the fall, the effects of raising the pool will slightly warm releases from Howard A. Hanson Reservoir because of the larger heat content in the raised pool. Monthly temperature release statistics are listed in Table B2 for all study years assuming the proposed rule curve and existing outlet.

31. The withdrawal limits for the raised pool reflected the minimal stratification in the bottom of the reservoir. The withdrawal zone consistently reached the bottom and was limited to approximately el 1,135 in the pool. The epilimnetic layers were effectively isolated from the withdrawal zone as shown in Figure 17.

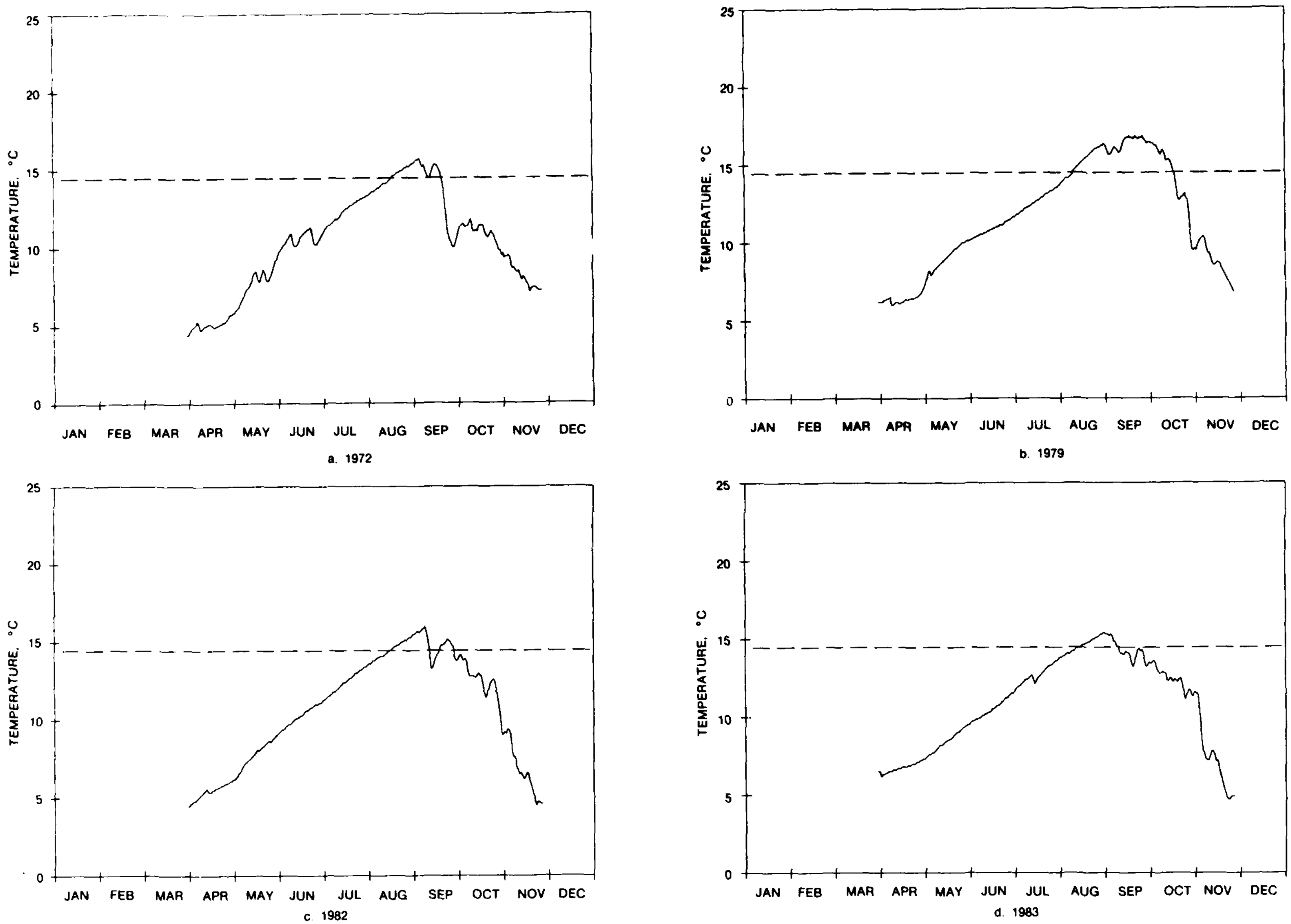

Figure 16. Calculated release temperatures

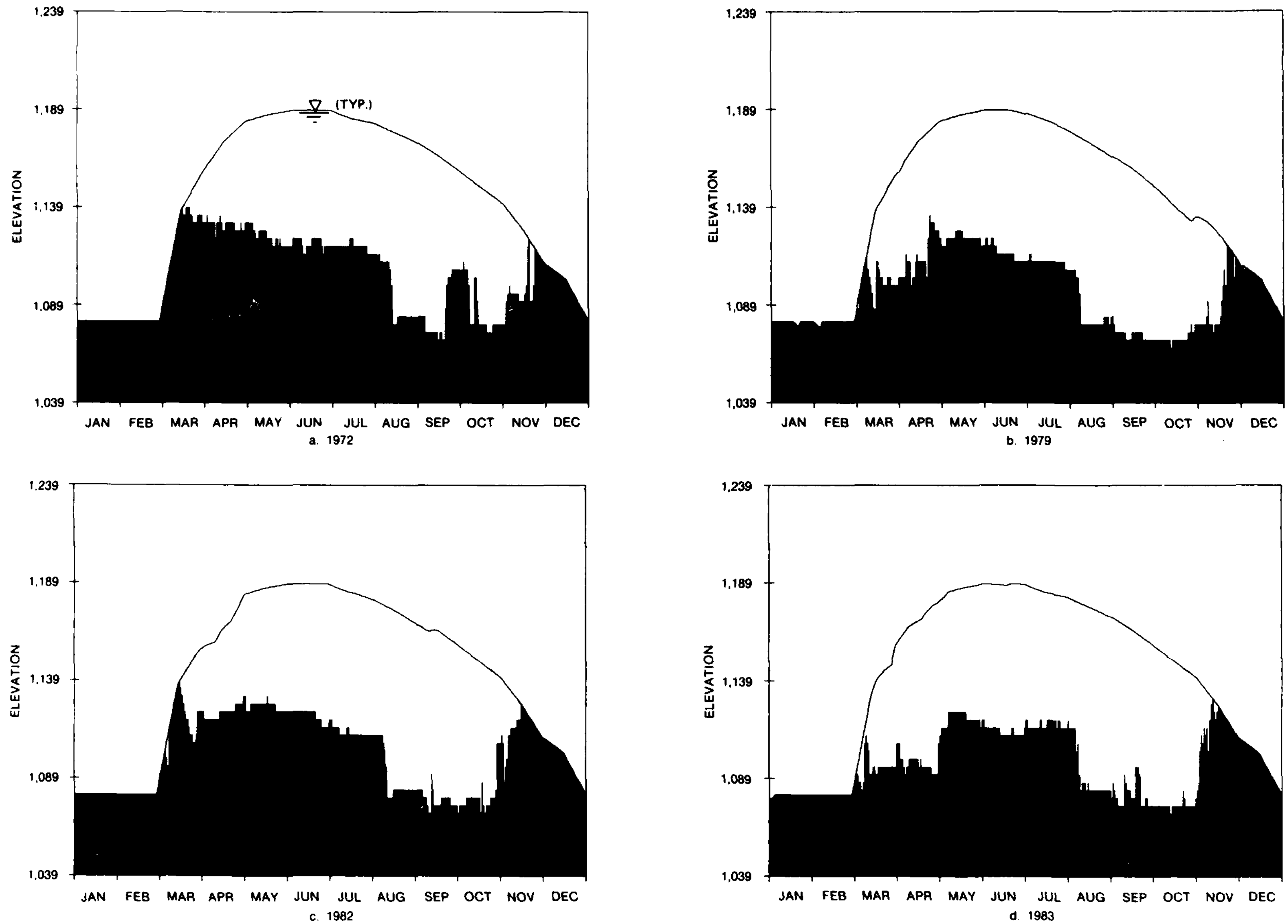

Figure 17. Withdrawal limits for existing outlet and raised pool

32. Warmer water was available for withdrawal much earlier in the spring for the raised pool, but the existing outlet structure was not capable of accessing this resource due to location of the ports. The capability to release epilimnetic water would not just warm spring releases but also conserve cooler water for release later in the summer and fall. Modification of the existing outlet structure would be required to reallocate the thermal resources available in the reservoir under the proposed operating scenario.

Impacts of Selective Withdrawal Operations

33. The existing project releases allow for establishment of a certain quality environment downstream from the dam. If the raised pool is put into effect, changes would be expected in the downstream environment as it seeks a new equilibrium in response to the modified release temperatures. The Green River downstream of Howard A. Hanson Dam supports a rich anadromous fishery resource. If the anticipated response of the downstream environment to modified release temperatures is unacceptable to resource managers, then several alternatives are available to minimize these impacts. One alternative is the incorporation of a multilevel selective withdrawal system to allow release of water to meet specified objectives. The chief advantage of a multilevel selective withdrawal system is flexibility in meeting release water quality objectives over a wide range of operating conditions.

34. The need for a multilevel outlet to compensate for pool raising on Cowanesque Lake was investigated by Holland (1982). His study, which involved the reallocation of flood-control storage for water supply use, determined the additional intakes needed to meet existing release temperatures. Similar conclusions were reached by Dortch (1981) in his investigation of Kinzua Dam in Pennsylvania and by Peters (1978) in his report of modifications to Flaming Gorge Dam in Utah. In the investigation of release water quality from Sutton Dam (George, Dortch, and Tate 1980), a riser was designed to improve water quality releases.

35. The addition of a port or ports higher in the pool at Howard A. Hanson Reservoir should allow releases to meet release temperature objectives downstream adequately. The withdrawal of water from the epilimnion will provide for warmer releases earlier in the year while conserving hypolimnetic water for release later in the year. The effectiveness of the outlet system

depends upon the type of withdrawal structure, withdrawal capacity, port size, port location, and number of ports together with operational criteria to achieve a given release water quality subject to the available resources.

Optimization of Outlet Structure Design

36. To arrive at an efficient outlet structure design for the raised pool, the number and location of additional intakes needed to meet release temperature objectives must be determined. The design of the outlet structure is greatly simplified through the coupling of mathematical water quality models like WESTEX to mathematical optimization techniques (Dortch and Holland 1984). This combination enables the consideration of numerous hydrological, hydraulic, meteorological, physical, and operation conditions in the formulation of tower design. Prior to the implementation of such optimization techniques, selective withdrawal intake configurations were based on judgment and experience of the design engineer. Optimized outlet configurations may involve fewer ports, as compared to traditionally accepted designs, to meet a given downstream temperature objective, thereby reducing both operational complexity and the costs associated with design, construction, and maintenance. Additionally, the use of optimization techniques should further enhance tower design by allowing systematic evaluation of the flexibility needed in the design for multiple or anticipated quality objectives.

37. The purpose of the mathematical optimization procedure is to systematically screen numerous outlet tower designs in terms of performance in meeting a specified release water quality criterion. The goal of releasing water with a temperature of no greater than 14.4° C was expressed earlier. This objective was modified slightly to represent the cyclical nature of available thermal resources. The objective temperature was defined as the naturally occurring Green River stream temperature as defined by a sine function up to a maximum temperature of 14.4° C where

$$\text{Water temperature} = 6.0 \times \sin\,(0.0174 \times \text{Julian day} - 2.234) + 8.0 \qquad (4)$$

This relationship was derived from available Green River temperature data as shown in Figure 18. Employing a cyclical objective temperature avoids

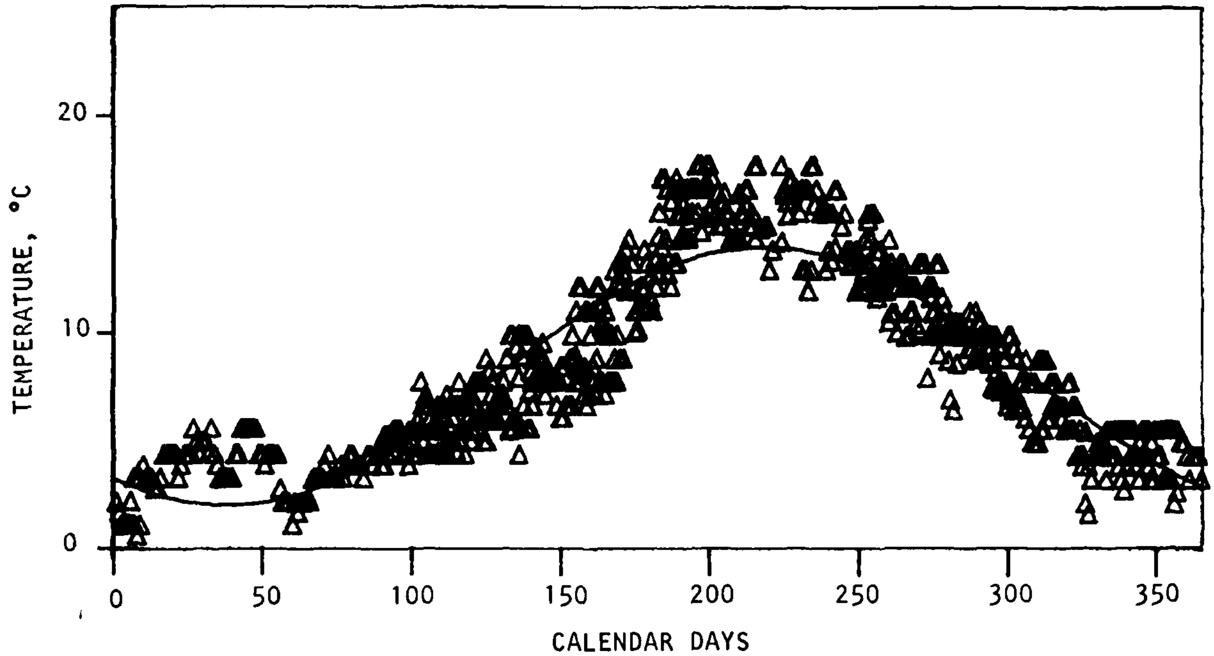

Figure 18. Green River temperature versus sine curve used as target temperature objective

temporal biasing of optimization results characteristic of constant-release temperature objectives.

38. A satisfactory measure of system performance must also be specified if optimum outlet configurations are to be determined. The objective function is a mathematical reflection of how well one possible decision (i.e., number and location of outlets) meets a given set of objectives. The objective function chosen in this study was the sum of squares of deviations between predicted release and target temperatures during the conservation period. Minimization of the objective function yields the optimal location of additional ports for release temperature control. This form of objective function was chosen since its minimization tends to produce outlet configurations that reduce the magnitude of objective deviations experienced. The formula chosen to represent the objective function is project dependent and may include mathematical representations of such factors as State and Federal water quality regulations, temporal weighting of deviations, or numerous water quality constituents.

39. To evaluate the potential impacts of adding selective withdrawal capabilities to Howard A. Hanson Reservoir, a type of withdrawal structure must be identified. Two alternative structures were considered for this

study. The first alternative investigated involved modifying the existing outlet works to include additional levels of ports connected to the 48-in. bypass conduit. Two operational policies associated with the modified outlet were investigated. A second alternative involved replacing the existing outlet system with a dual wet well structure with two water quality collection wells. The design of both structural alternatives was based upon the application of the reservoir model coupled with mathematical optimization techniques.

Modification of the Existing Outlet Structure

40. The existing structure could be modified to provide selective withdrawal capabilities if a riser is added to the existing 48-in. bypass conduit. This modification would maintain the existing outlet at el 106 while adding additional ports at higher elevations. Ports located at different pool levels could be activated to withdraw water of a given quality. Only a single 6- by 6-ft outlet leading to the 48-in. bypass could be activated at one time. If flow control did not change, the maximum release through this system would be about 600 cfs at maximum conservation pool el 1,189. Any scheduled release in excess of this amount would have to be passed by the sluiceway. The operational policy associated with the modified outlet would involve releases through the 48-in. bypass during the conservation season. The drawback of this design is that only discrete levels of withdrawal are possible unless measures providing for single wet well blending are incorporated into the design.

41. The number and location of additional ports were addressed by applying the reservoir optimization model. Scenarios involving the addition of one, two, three, and four ports were investigated. The utility of a given design was defined as the summation of squared deviations of the daily release temperature from the daily target temperature over the conservation period. The optimal locations of the additional ports and the associated objective function value are given in Table 1 for each of the study years simulated.

42. The performance of the proposed outlet structure improved as ports were added to the design as indicated by decreasing objective function values for an increasing number of ports. The low-flow year 1979 exhibited the poorest release conditions relative to the objective function. Warmer atmospheric conditions coupled with little watershed runoff during the spring and summer

resulted in a smaller amount of colder water resources being available during that year. The design involving three additional ports was selected as the best design since the addition of a fourth port provided only marginal benefits. The three-port configuration provided additional operational flexibility over the two-port configuration by providing releases over a wider range of pool levels. The optimal location of ports near el 1,139 and 1,119 was consistent for all study years. A third port located at el 1,159 is recommended to provide upper level releases during the spring and early summer. A port near this location was required during simulation of conditions for the average year (1982) to meet target release temperatures.

43. The in-reservoir thermal characteristics were significantly altered through the release of epilimnetic water from the proposed additional ports. The proposed ports began operation by the month of May and commonly required sluiceway releases to meet scheduled releases during this period (Figure 19). The depression of the thermocline was delayed through the summer months by upper level releases. As the thermocline progressed more deeply in the pool, lower level ports were activated to release cooler water. It should be noted that once the existing port at el 1,073 was activated, hypolimnetic water warmed quickly. The stability of stratification for the raised pool with a single wet well (Figure 20) exhibited patterns similar to those for the raised pool with the existing structure (Figure 15). There is a minor difference in that the stability is somewhat stronger in the single wet well scenario. This stronger stability is due to the capability of the wet well to release epilimnetic water, thereby retaining a stronger degree of stratification through the summer.

44. Project release temperatures were highly discontinuous when outlet level changes were performed during the summer months (Figure 21). Day-to-day release temperature fluctuations as great as 6° C were experienced during summer outlet changes. These conditions may be much more detrimental to the downstream ecological environment than conditions resulting from a continuous lower level release. This outlet design does provide for warmer releases earlier in the year and a shorter period of release water temperature exceeding 14.4° C for years 1972 and 1983 compared to anticipated conditions for the existing outlet. The average monthly releases during April through July were up to 1.4° C warmer than conditions expected with the raised pool and existing outlet configuration while releases in August through October were up

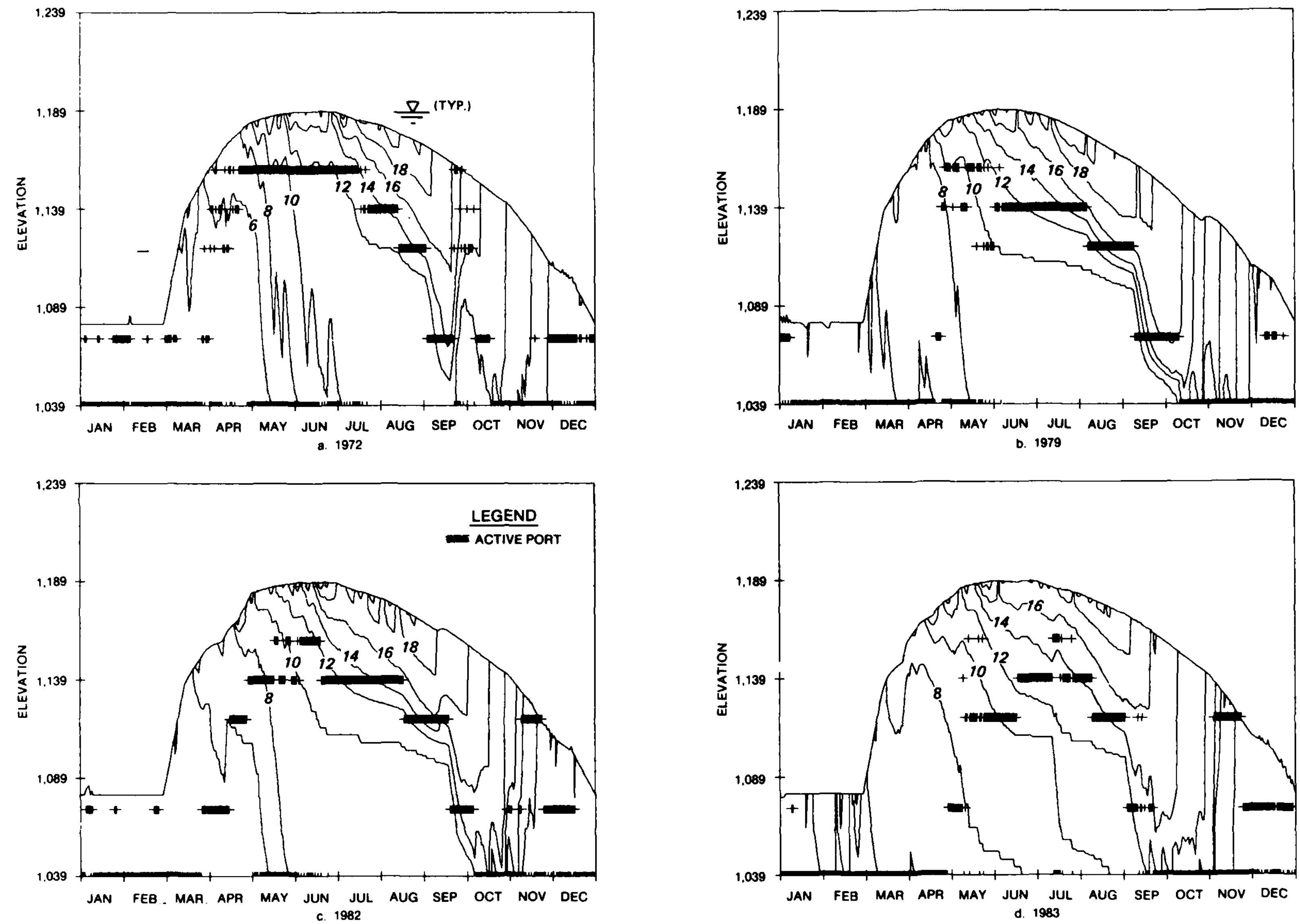

Figure 19. Seasonal temperature contours with raised pool and single wet well outlet

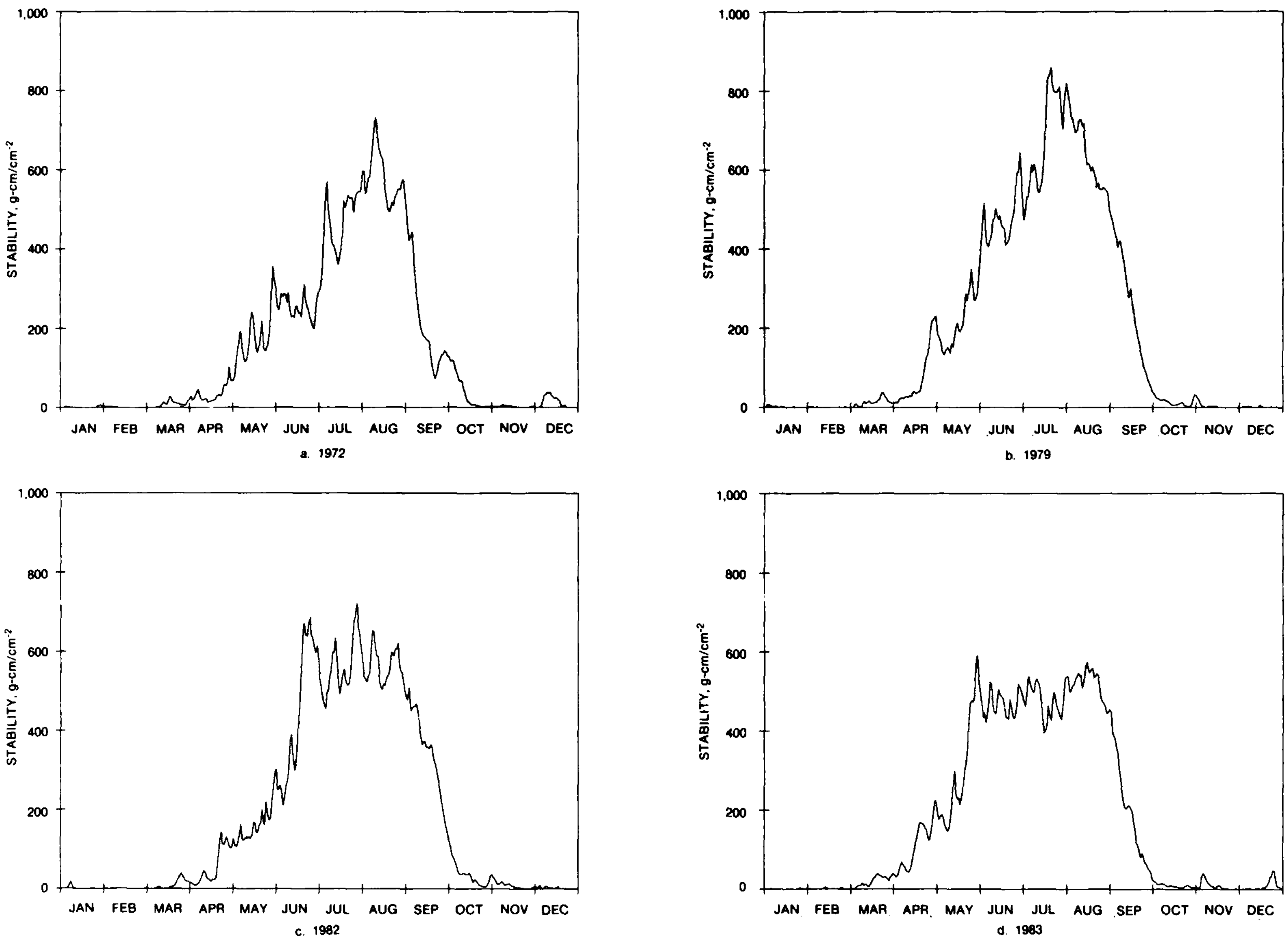

Figure 20. Stability of stratification for raised pool with single wet well

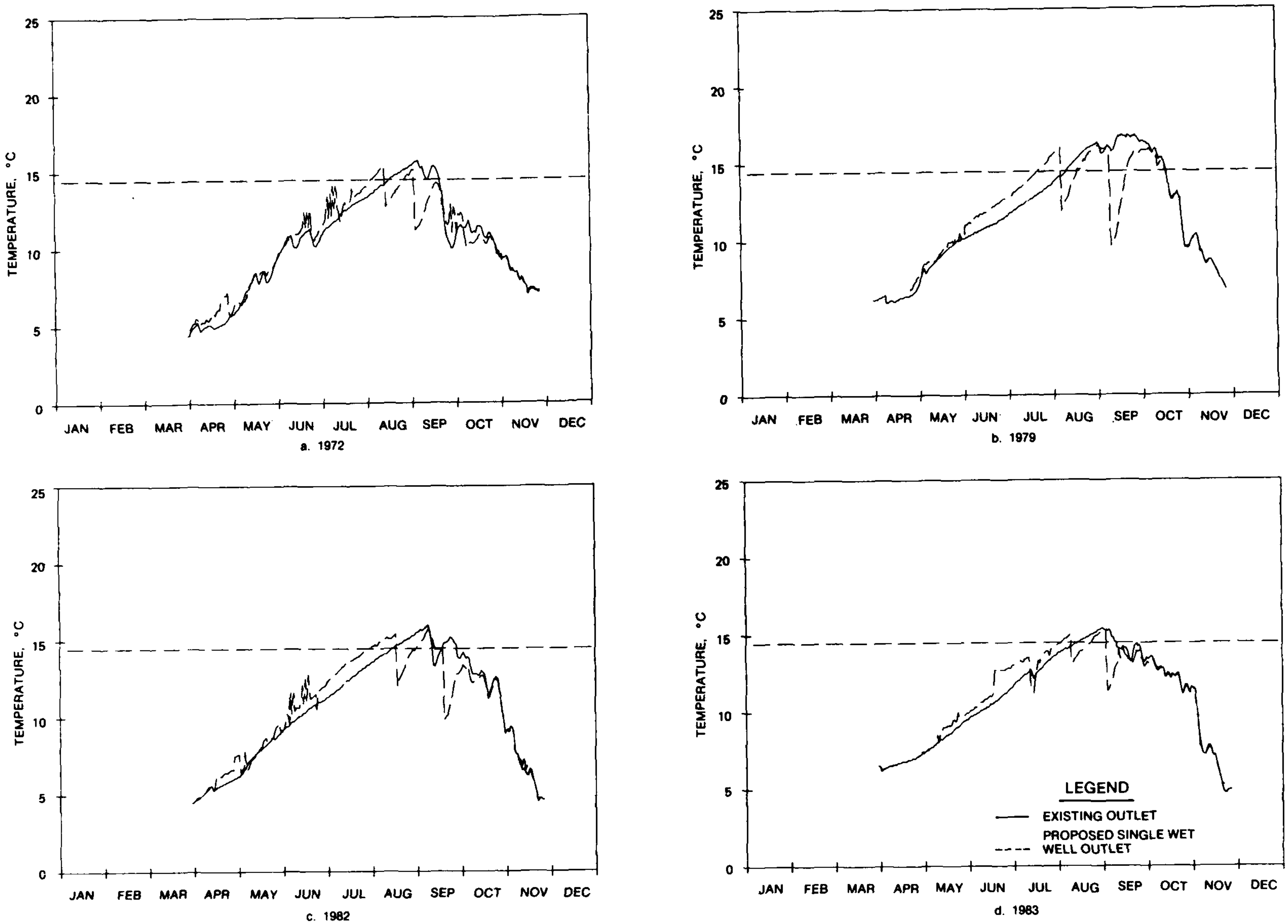

Figure 21. Calculated release temperature with raised pool for the existing and proposed single wet well outlet

to 2.3° C cooler as listed in Table B3. Temperature deviations from naturally occurring Green River temperatures as estimated using Equation 4 are illustrated in Figure 22.

Sluiceway Blending with Modified Outlet Structure

45. The major shortcoming of the modified single wet well structure is its assumed inability to blend water from different pool levels. The potential to blend releases using the modified outlet structure at Howard A. Hanson Reservoir exists if operational policy concerning sluiceway releases is modified. This scenario assumes the sluiceway control gate could be throttled to release a discharge that, when combined with the bypass release, meets a specific target temperature. In the past, both systems have been used together to meet only release quantity constraints. Hydromechanical constraints such as gate vibration and debris blockage may prevent the use of the flood-control system for release temperature control. This type of water quality outlet would be more complicated to operate since frequent gate changes would be required to maintain the appropriate distribution of flow between systems. However, the benefits of this scenario would include greater continuity and control over release temperature characteristics.

46. Once again, the number and location of additional ports were investigated using the optimization model assuming sluiceway operation to meet water quality objectives. Scenarios involving the addition of one and two ports were investigated. The optimal locations of the additional ports and the associated objective function value are given in Table 2.

47. The performance of the modified outlet structure with sluiceway blending was better than the no-port condition (existing condition) or the nonblending alternative as indicated by the smaller objective function values for the same number of additional ports (Tables 1 and 2). The addition of a single port in the epilimnion provided access to warmwater resources to blend with cooler low-level releases. The optimal location of a single port ranged from el 1,159 to 1,175. The higher the elevation of this port, however, the shorter the period of its operation due to fluctuating pool levels. Therefore, the lower range of optimal single-port location (el 1,159) was selected as the best design.

48. Very little improvement resulted from the addition of a second port

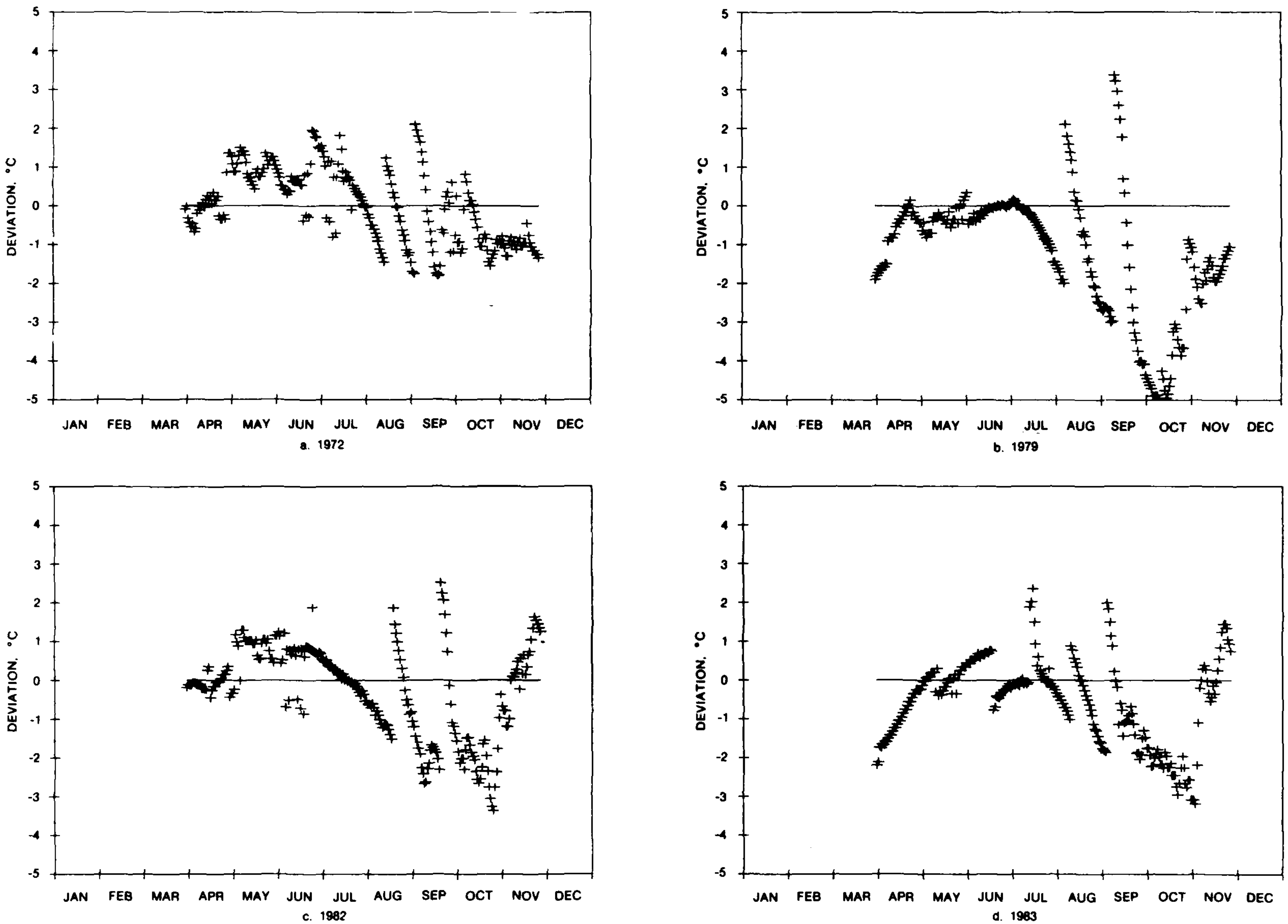

Figure 22. Daily release temperature deviation from objective with single wet well outlet

in terms of temperature release characteristics. The second port did not significantly improve releases because very little stratification existed when the pool dropped below the upper port, thus minimizing any benefits associated with retaining selective withdrawal capabilities. However, the addition of a second port below the optimal single-port location may be necessary to maintain an epilimnetic release if pool drawdown in excess of simulated conditions is anticipated. Other water quality concerns, such as turbidity, may also dictate the need for a second port located in the upper pool.

49. The in-reservoir thermal characteristics associated with this scenario (Figure 23) were similar to conditions simulated for the raised pool with the existing outlet due to the similar operational pattern requiring hypolimnetic releases. A strong thermocline did not develop under this operational scheme. The pool was warmed at a slower rate due probably to the use of some epilimnetic releases as opposed to strictly hypolimnetic releases in the previous case. As midsummer approached, releases strictly from the upper level were warmer than the target release temperatures; thus lower level releases were required at this point to blend with epilimnetic releases. This type of operating condition was continued throughout the summer with increasing rates of hypolimnetic releases. Hypolimnetic releases exhausted cooler water resources to the point where the minimum pool temperatures by mid-September approached 14° C. At this point, the bottom level release became the sole outlet. This condition may lead to release temperatures significantly warmer than objective temperatures as simulated in 1979. The stability of stratification for the proposed outlet (Figure 24) is similar to the single wet well raised pool scenario (Figure 20). Although there are obvious differences in the seasonal temperature contours for both cases, the impacts to the stability of the stratification are minimal.

50. Release temperatures from this scenario closely met objective temperatures through the summer months (Figure 25). The variability in release temperatures decreased once the pool was filled during the spring. Storm events did cause some deviations from objective release temperatures as illustrated by the discontinuities during June and July of 1972. The selective withdrawal capabilities from the project were effectively eliminated at the end of the summer when coldwater resources were exhausted. This occurrence was represented by the renewed variability in project releases during the fall months and increase in the deviation between target and release

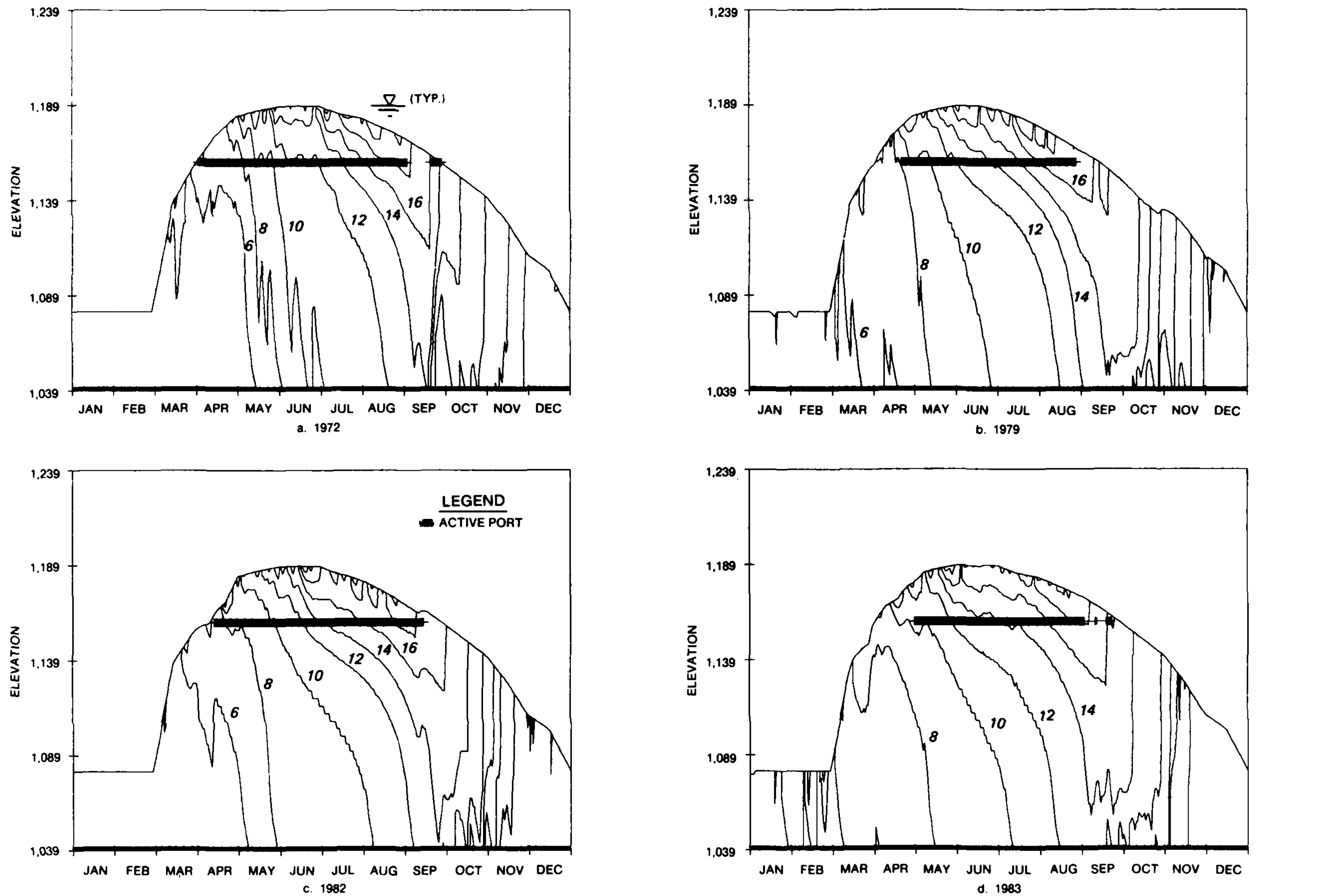

Figure 23. Seasonal temperature contours with raised pool and single wet well outlet with sluiceway blending

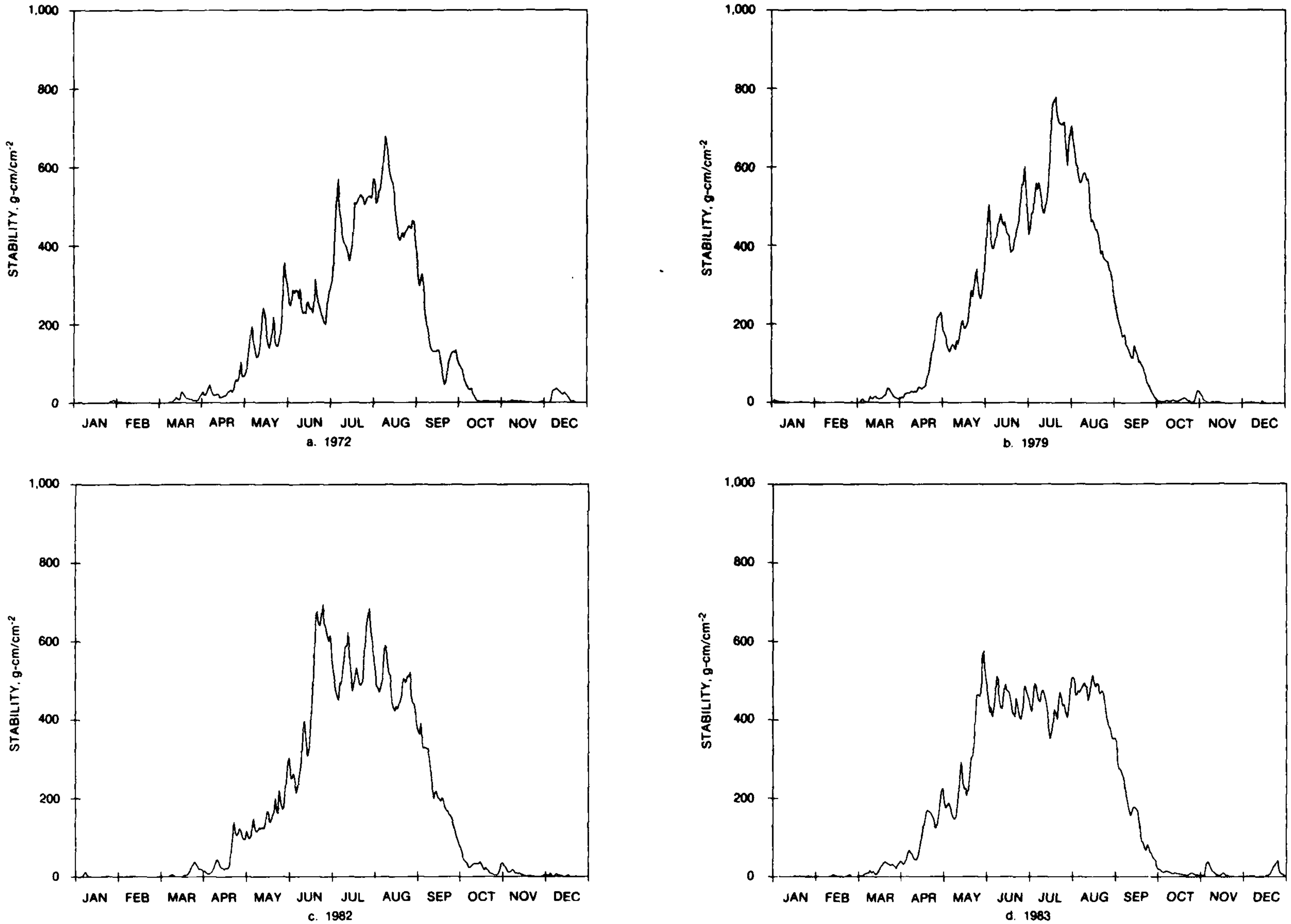

Figure 24. Stability of stratification for raised pool with proposed outlet

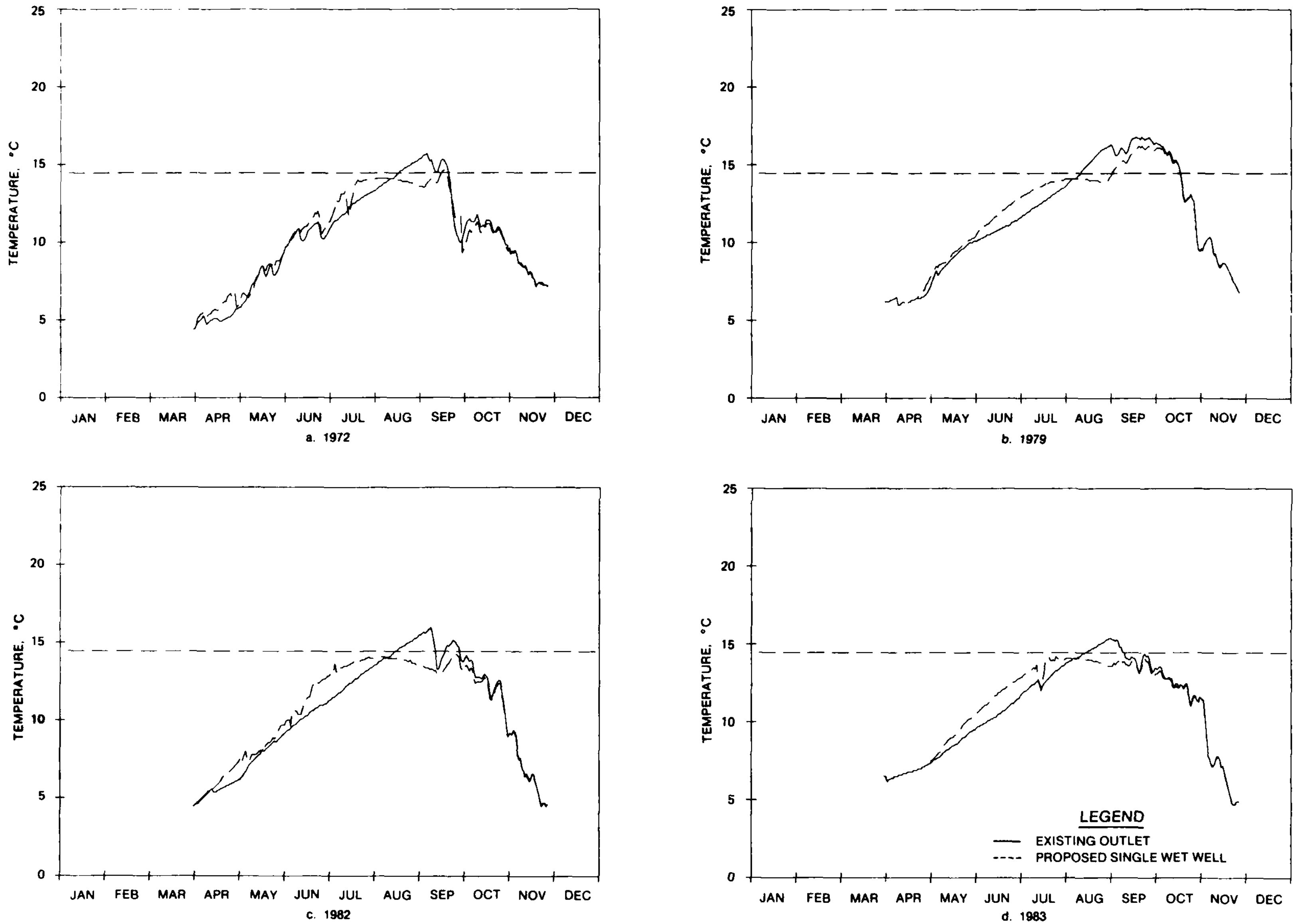

Figure 25. Calculated release temperatures with raised pool for the existing and proposed single wet well outlet with sluiceway blending

temperatures as shown in Figure 26. Spring and summer release temperatures were warmer than the conditions expected for the existing outlet structure under the same rule curve while late summer and fall releases were significantly cooler as shown in Table B4. Maximum project releases were kept at or below 14° C except for the low-flow year 1979. Further, this alternative did not experience the sharp discontinuity in project releases as was simulated for the modification of the existing outlet structure without blending.

Dual Wet Well Selective Withdrawal Tower

51. Replacing the existing outlet tower with a dual wet well outlet structure with multilevel ports would allow additional control over release temperature characteristics. The dual outlet structure would enable outlet gate changes to meet a desired release rate through each wet well. If the desired objective temperature exists in the pool, it may be possible to blend water from both outlets to meet project release goals. This outlet design may have more flexibility in conserving cooler water resources for releases later in the year than the blending scenario discussed earlier because dual wet wells provide for blending between two upper levels, thereby conserving hypolimnetic resources.

52. The number and locations of ports in each wet well were again investigated through optimization. Each wet well was assumed to have the capacity of the existing 48-in. bypass conduit. The characteristics of the flood-control system were not altered. Scenarios involving the design of one and two ports in each wet well were investigated. The optimal port locations of each design and associated objective function value are given in Table 3.

53. The objective function values for the single port per wet well indicated a considerable improvement in meeting release temperature criteria as opposed to operation of the existing structure (zero-port scenario in Table 3). The optimal port elevations for the single port design were grouped around el 1,084 and 1,159 for study years 1979, 1982, and 1983. Ports were located higher in the pool for the study year 1972 because of the abundance of cooler inflows. One limitation of the single-port design is that the port may be operational for only a portion of the year due to fluctuating pool elevations. Also, depletion of cooler water resources via the low-level release was required to meet release targets once stratification developed. This

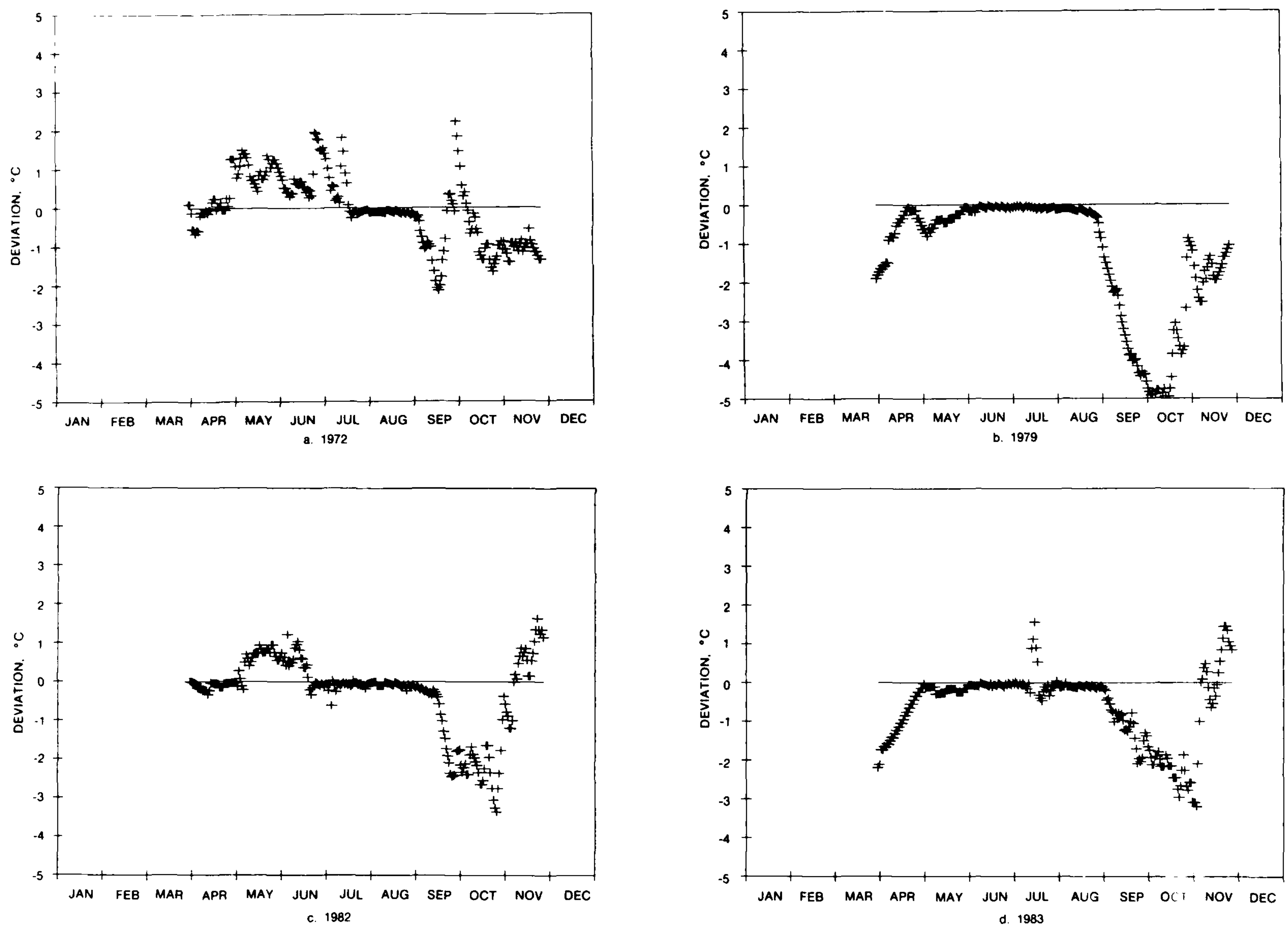

Figure 26. Daily release temperature deviation with raised pool for the existing structure and proposed single wet well outlet with sluiceway blending

operational policy exhausted the availability of cooler water for release later in the year for all study years. Both of these limitations were mitigated when intermediate-level outlets were included in the design. The two-port design provided additional flexibility in meeting release temperature objectives except for the low-flow year 1979: thermal (cool bottom) resources were not available during 1979 to meet release temperature goals later in the fall. This alternative does provide operational flexibility to minimize the impacts associated with thermal resource deficits.

54. Optimal port locations varied significantly between study years for two ports per wet well configuration. The critical year in terms of release temperature criteria was the low-flow year 1979. The addition of a second port in each wet well resulted in no improvement in performance for 1979. The best performance was achieved by providing an upper level release around el 1,157 and a lower level release near el 1,080 for this year. A design using two ports per wet well will provide similar release characteristics if outlets are provided over this range of elevations.

55. Fo·· both study years 1982 and 1972, release performance was improved if outlets higher in the pool were provided for accessing warmer water earlier in the spring. The optimal port configuration associated with the study year 1982 was recommended as the best dual wet well design since it also approximated the levels of release required during the years 1979 and 1983. This configuration of two ports per wet well will provide reliable access to epilimnetic water during the spring and summer months. As the thermocline becomes depressed, intermediate and lower level outlets are available for blending project discharges to achieve specific release temperature objectives. Thus, the optimum outlet configuration included port locations at el 1,171 and el 1,125 in one wet well and el 1,153 and el 1,079 in the second wet well. This outlet tower design was simulated for all the study years with only a small degradation in release performance over that of the optimal design given for the individual years.

56. The in-reservoir characteristics resulting from the operation of the proposed dual wet well outlet tower (Figure 27) were similar to the conditions that developed with the modified outlet structure without blending (Figure 23). This similarity was due to reliance on epilimnetic releases in meeting objective release temperatures. The depression of the thermocline during the summer was gradual due to upper level release while the

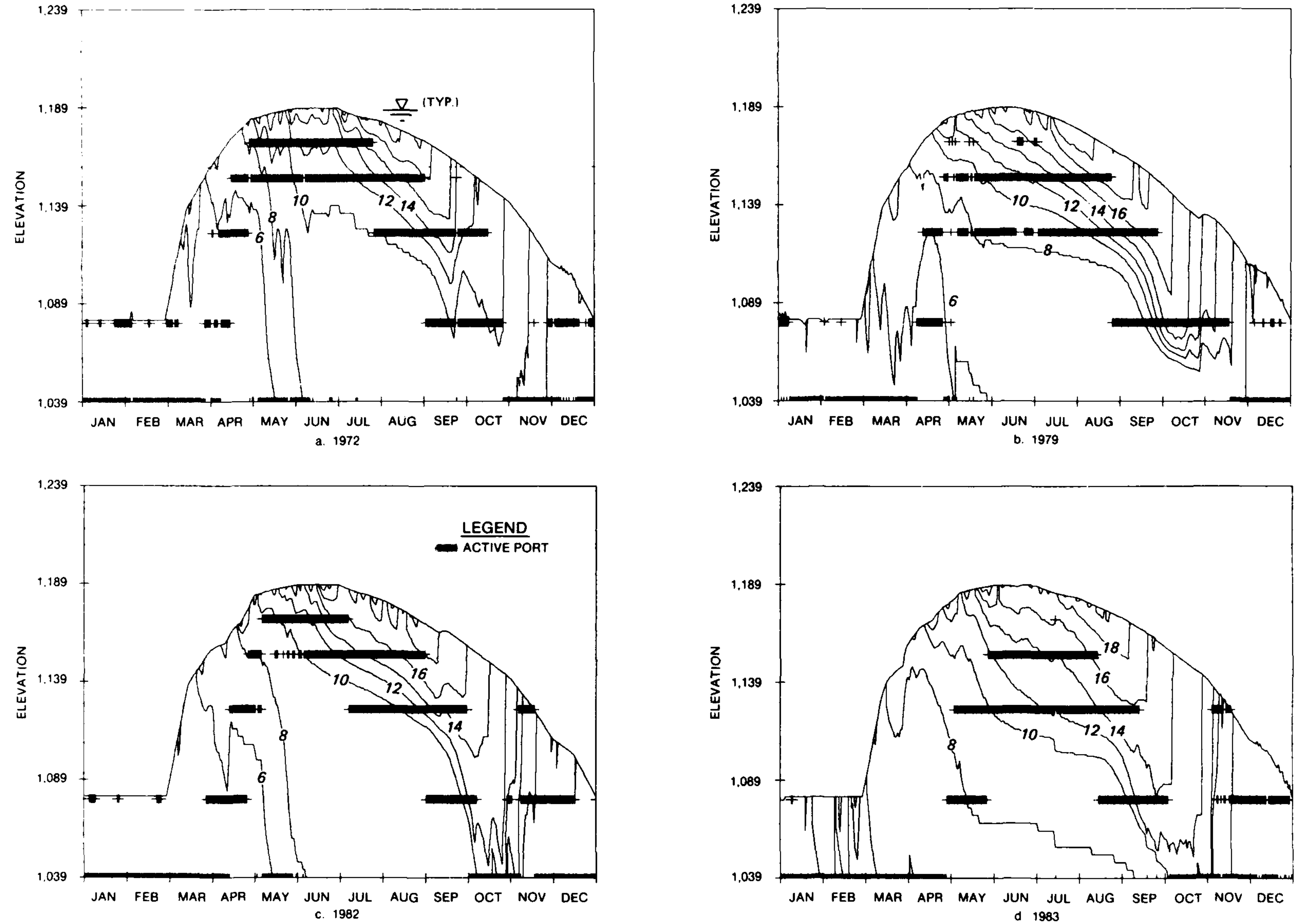

Figure 27. Seasonal temperature contours with raised pool and dual wet well outlet

hypolimnetic temperatures remained almost constant during this period. As cooler water was released in the fall months, the thermocline was drawn down. The reservoir cooled off rapidly from top to bottom during October as indicated by an increase in project release temperatures. With the exception of 1972, coldwater (hypolimnetic) resources in the reservoir became exhausted by the month of October as occurred during all previous simulations. The average reservoir temperature during this period approached 14° C. The stability of stratification for this scenario (Figure 28) was much stronger than previous scenarios. With the capability to draw water from two ports to meet a release temperature, water is drawn from a larger number of layers in the pool. This capability minimizes the effect of withdrawal zone formation in any one layer, thus allowing a more stable thermal profile to be maintained.

57. Release temperatures from the dual wet well outlet were able to meet target releases closely for most of the conservation period (Figure 29). Resources for blending to a specific release objective temperature were available throughout the summer and into the early fall. Cool-water resources generally became exhausted during September resulting in releases warmer than objective temperatures. The maximum project release temperature was limited to 14.4° C for all years except 1979. Release temperatures in May, June, and July were on average 0.5°, 1.2°, and 1.1° C warmer, respectively, than conditions for the operation of the existing outlet structure with storage reallocation (Table B5). Release temperatures during August, September, and October were predicted to be cooler than those predicted for the existing wet well configuration. The largest impact occurred during September when releases were from 1° C to 3.6° C cooler from the dual wet well outlet compared with those of the existing outlet. Releases during the fall continued to be warmer than the naturally occurring stream temperature as indicated in Figure 30. The single wet well outlet with sluiceway blending, which was discussed in the previous section, displayed similar trends; however, the dual wet well scenario, with greater operational flexibility, had smaller objective function values for all years except 1979. These improvements were observed primarily in the fall since that was when resource limitations exhibited the strongest impact on release temperatures. Deviations from release temperature objectives were observed during the low-flow year 1979 for all outlet configurations simulated. However, the operational flexibility of the dual wet

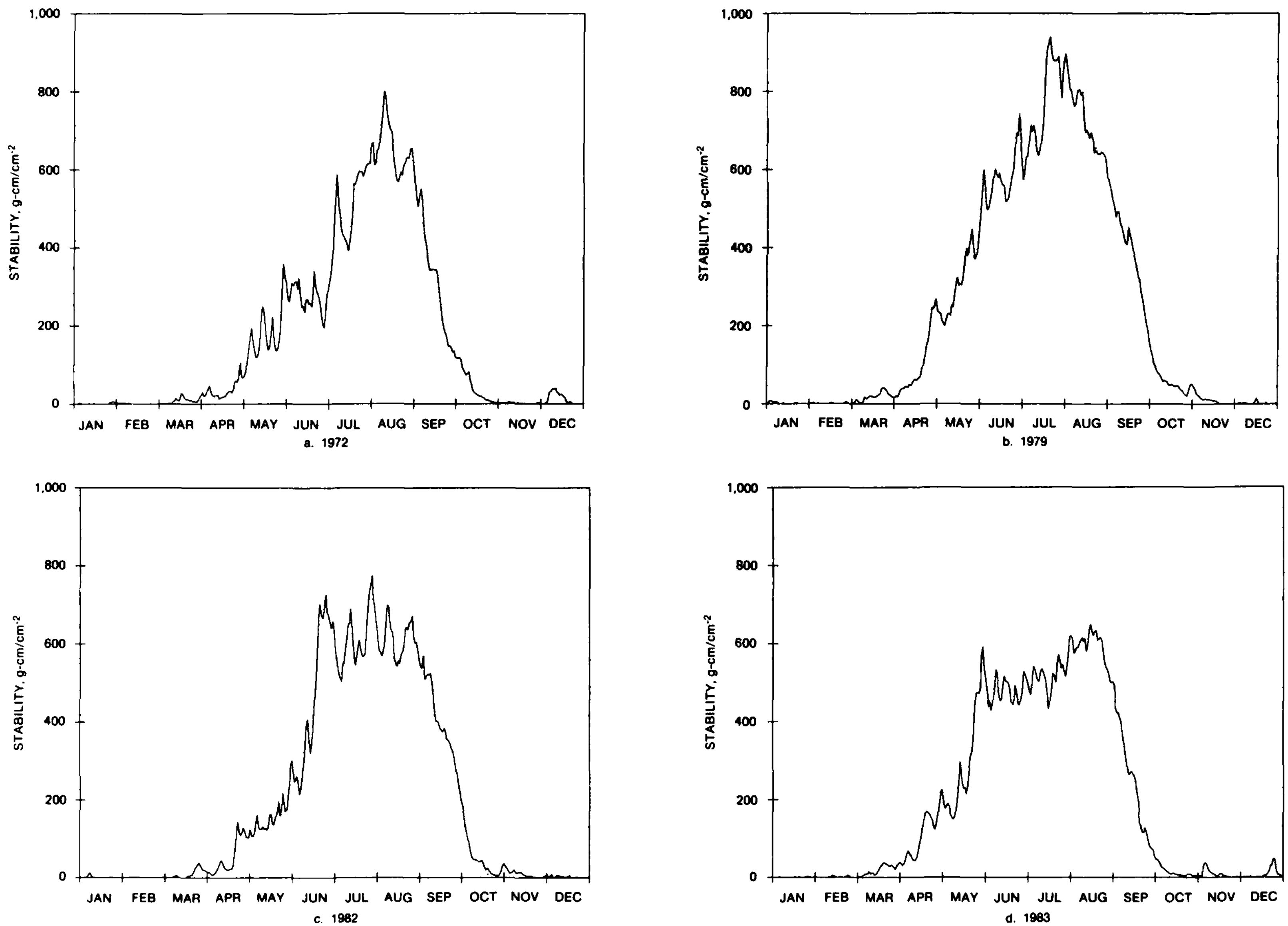

Figure 28. Stability of stratification for raised pool with dual wet well

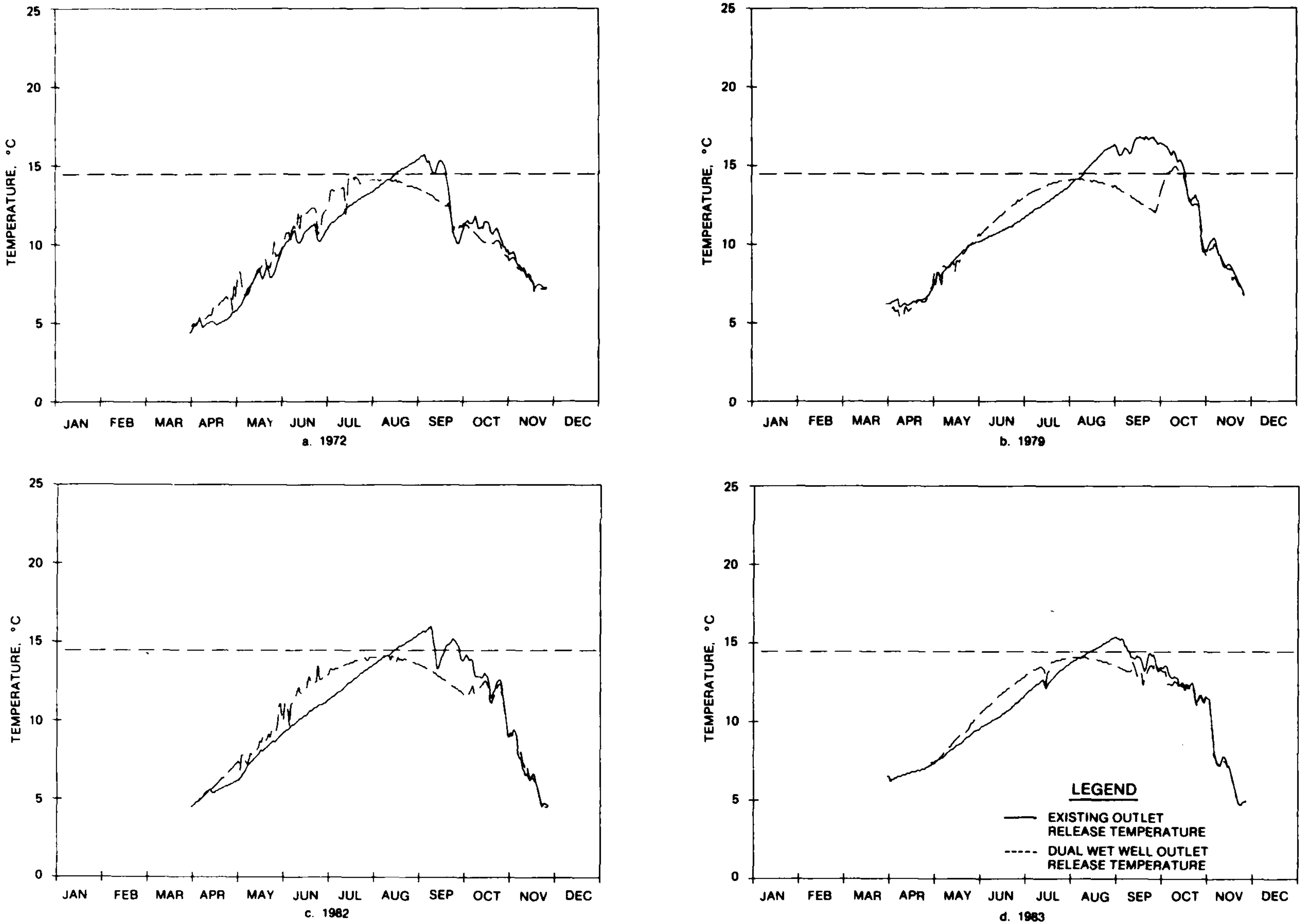

Figure 29. Calculated release temperature with raised pool for the existing and dual wet well outlets

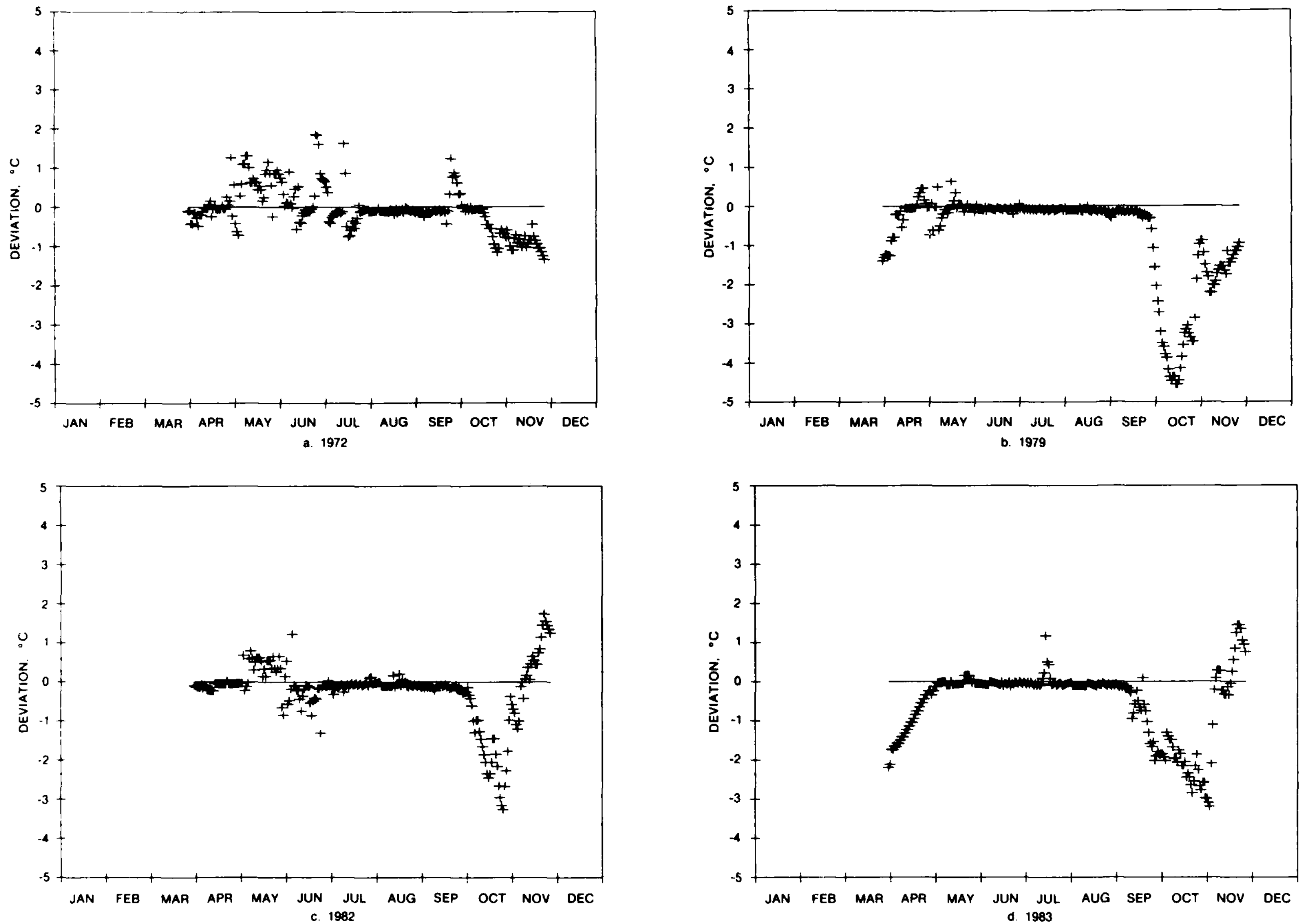

Figure 30. Daily release temperature deviation from objective with single wet well outlet with sluiceway blending

well structure can be used to redistribute the available thermal resources to minimize adverse impacts to the downstream environment.

58. To illustrate the operational flexibility of the dual wet well outlet tower, release temperature objectives were changed to a constant 14.4° C during the conservation period. This criterion resulted in the operation of the two uppermost ports throughout most of this period (Figure 31). This operational criterion also resulted in a stronger thermocline coupled with larger coldwater storage. Maximum release temperatures were limited to near 14.4° C for all study years (Figure 32). The period of 14.4° C temperature release was extended several months into the summer compared to the previous release objective. Spring release temperatures were up to 5° C warmer than releases predicted for the existing outlet with the raised pool (Table B6). During the fall, when the lake began to cool off, release temperatures were slightly cooler than the previous operating conditions due to the conservation of hypolimnetic water.

59. The six operating scenarios have been discussed relative to their ability to meet a given release temperature objective. However, to summarize the effects of each scenario on the release temperature, the average monthly release temperature for April through November was compiled by year for each scenario (Table C1). These results indicate the releases from the raised pool with the existing structure (B series) are much cooler in the spring and early summer months than existing releases (A series). With the addition of a single wet well (C series), warmer release temperatures, similar to the existing conditions (A series), were observed during the spring months while late summer and fall releases were significantly cooler. The addition of sluiceway blending with the single wet well (D series) added the operational ability to blend water from two ports in the stilling basin, which provides for a continuity of release temperatures not characteristic of the nonblending alternatives. The dual wet well configuration (E series) was able to maintain the coolest release temperatures in August through November for most of all the years simulated. Although average release temperatures for the remaining months were similar to those for the single wet well with the sluiceway blending, the ability to maintain the cooler release in the late summer and early fall makes this the better overall structural configuration. The flexibility of the dual wet well alternative was further illustrated by employing a constant release temperature objective of 14.4° C (F series) throughout the year.

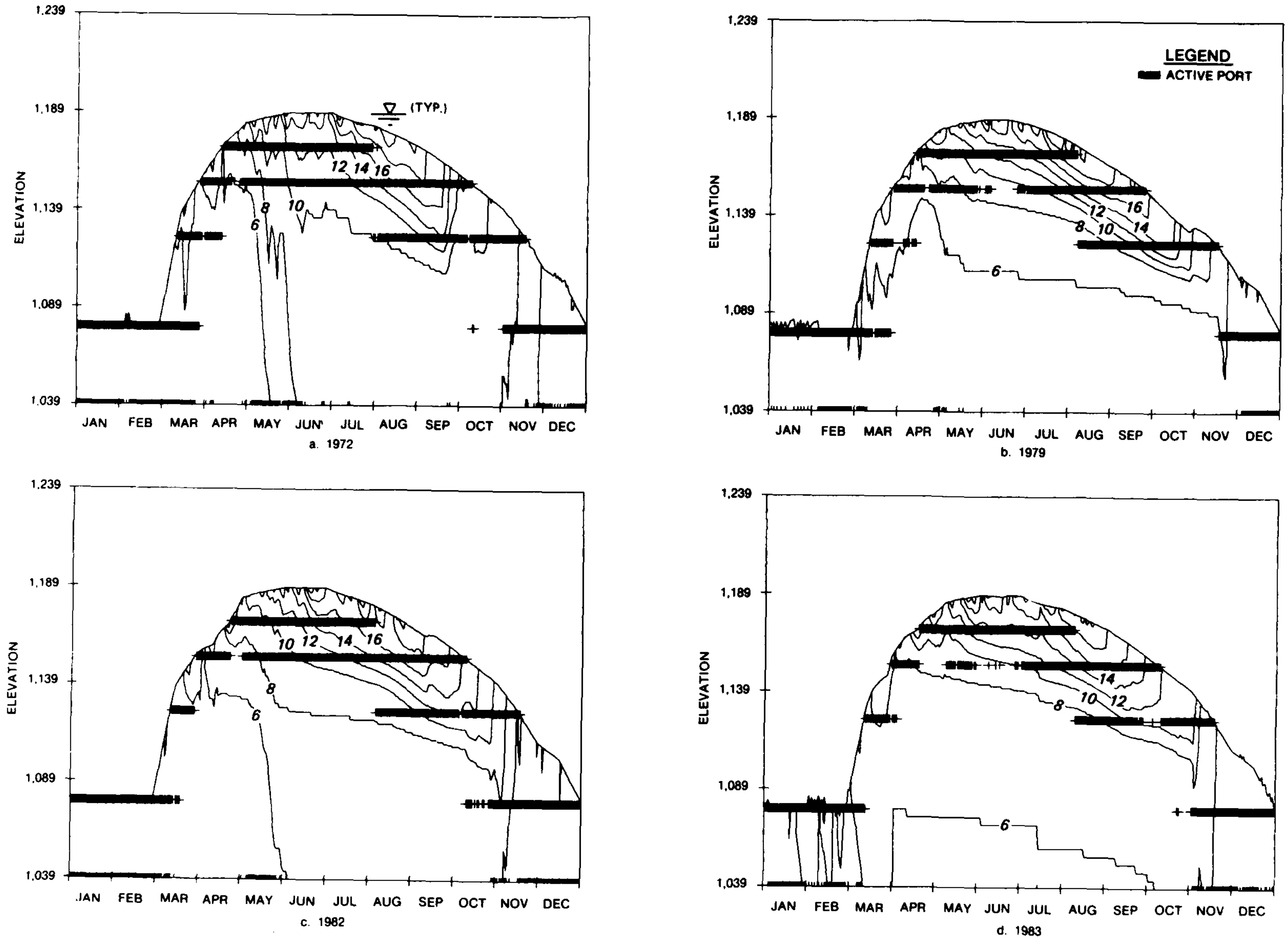

Figure 31. Seasonal temperature contours with raised pool and dual wet well outlet with 14.4° C temperature objective

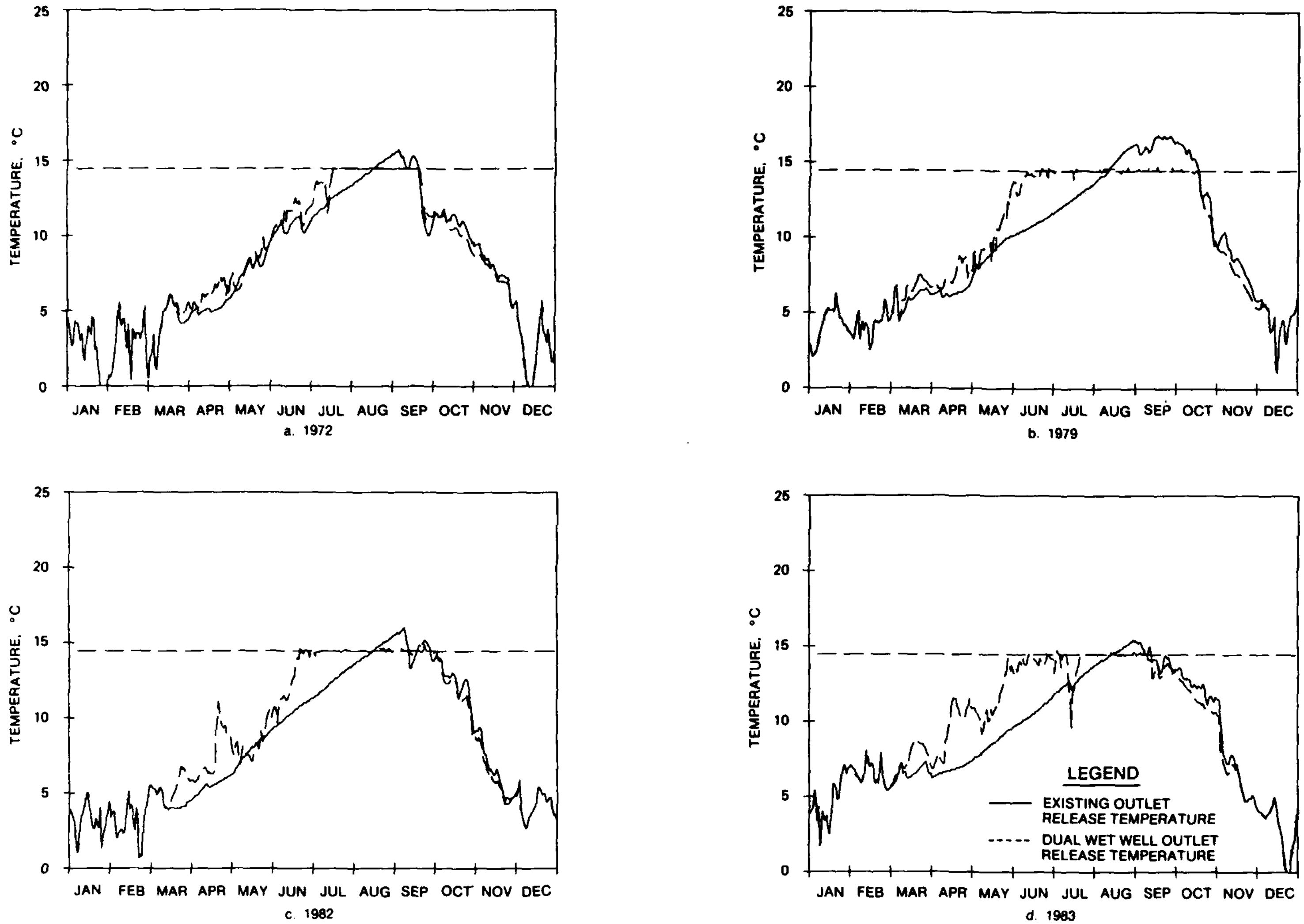

Figure 32. Calculated release temperature with raised pool for the existing and dual wet well outlets with 14.4° C temperature objective

The results indicated that the dual wet well with its operational flexibility could significantly extend the period when 14.4° C releases can be made.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

60. Modifying the operating policy at Howard A. Hanson Reservoir by initiating spring storage earlier and increasing the maximum conservation pool will impact the project releases and in-reservoir thermal characteristics. The increased volume and surface area of the reservoir will result in a significant increase in total heat content of the reservoir. The deeper conservation pool will provide for larger temperature gradients to develop from top to bottom, resulting in stronger stratification and increased water column stability. Release temperatures from the raised pool through the existing outlet works will be cooler during the spring and summer but slightly warmer during the late summer and fall. The maximum release temperature would be reduced if the proposed storage reallocation is implemented. The existing outlet configuration, however, has little flexibility in altering the release water quality characteristics from the raised-pool project. During low-flow years, late summer and fall release temperatures may significantly exceed downstream temperature objectives.

61. The addition of selective withdrawal capability through epilimnetic releases provides a means of effectively managing the thermal resources in the reservoir. The location of an additional port in the epilimnion allows warmer surface water to be released earlier in the spring while conserving cooler water resources. A single wet well structure with single-port operation may not provide the desired degree of control over release temperatures under the anticipated stratification. Storage reallocation will result in sufficient stratification to warrant blending releases from multilevels. A dual wet well outlet structure with two ports per wet well will provide the operational flexibility required to meet release temperature objectives for most of the hydrometeorological conditions simulated. This outlet configuration will also provide latitude in scheduling releases to meet other water quality objectives such as turbidity as well as providing the maximum degree of stability of stratification. For certain low-flow years, Howard A. Hanson Reservoir will be resource limited. For these events it is critical to manage the available thermal resources to minimize the damage to the downstream environment. Dynamic optimization procedures when used in conjunction with the numerical reservoir model can also provide operational guidance for mitigating the damage caused by release temperatures deviating from project objectives.

62. The recommendation that best meets the stated objectives therefore includes a dual wet well outlet structure with ports located at el 1,171 and el 1,125 in one wet well and el 1,153 and el 1,079 in the second wet well.

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Table 1

Optimal Port Elevation and Objective Function Value for Single Wet Well Outlet Configurations

Additional Ports	1972 Port El	1972 Objective Function Value	1979 Port El	1979 Objective Function Value	1982 Port El	1982 Objective Function Value	1983 Port El	1983 Objective Function Value
0	--	729	--	1,223	--	520	--	372
1	1,132	582	1,111	966	1,123	607	1,123	336
2	1,147	379	1,136	808	1,163	390	1,133	242
	1,125		1,115		1,139		1,111	
3	1,145	351	1,139	738	1,163	274	1,136	219
	1,125		1,118		1,139		1,116	
	1,113		1,092		1,119		1,103	
4	1,142	356	1,139	722	1,158	212	1,151	186
	1,129		1,119		1,140		1,136	
	1,117		1,096		1,130		1,123	
	1,098		1,083		1,112		1,110	

Table 2

Optimal Port Elevation and Objective Function Value for Single Wet Well with Sluiceway Blending

Additional Ports	1972 Port El	1972 Objective Function Value	1979 Port El	1979 Objective Function Value	1982 Port El	1982 Objective Function Value	1983 Port El	1983 Objective Function Value
0	--	729	--	1,223	--	520	--	372
1	1,175	140	1,159	805	1,167	216	1,1[illegible]9	224
2	1,176	140	1,159	805	1,182	185	1,159	222
	1,144		1,063		1,158		1,130	

Table 3

Optimal Port Elevation and Objective Function Value for Dual Wet Well Outlet Structure

Ports Per Wet Well	1972			1979			1982			1983		
	Port El		Objective Function Value	Port El		Objective Function Value	Port El		Objective Function Value	Port El		Objective Function Value
	Well 1	Well 2		Well 1	Well 2		Well 1	Well 2		Well 1	Well 2	
0	--	--	729	--	--	1,223	--	--	520	--	--	372
1	1,177	1,099	182	1,157	1,080	817	1,162	1,076	217	1,160	1,090	216
2	1,182 1,108	1,145 1,065	81	1,157 1,097	1,104 1,075	805	1,171 1,125	1,153 1,079	97	1,158 1,124	1,138 1,084	164

APPENDIX A: COMPUTATION OF THE RELIABILITY INDEX

1. The reliability index (RI)* was proposed by Leggett and Williams (1981) as a general test that can be used to evaluate the correspondence, or precision of fit, between predicted values from mathematical models and observed data. Thus, the test allows inference of a model's predictive capability. An interpretation of the index is that it indicates, in some sense, the degree to which predictions and observations agree. An RI of 1.0 indicates a perfect agreement, and the RI increases as predicted and observed values diverge. The RI is computed from

$$RI = \frac{1 + \sqrt{\frac{1}{N} \sum_{t=1}^{T} \sum_{n=1}^{N} \left[\frac{1 - (Y_{tn}/X_{tn})}{1 + (Y_{tn}/X_{tn})} \right]^2}}{1 - \sqrt{\frac{1}{N} \sum_{t=1}^{T} \sum_{n=1}^{N} \left[\frac{1 - (Y_{tn}/X_{tn})}{1 + (Y_{tn}/X_{tn})} \right]^2}} \tag{A1}$$

where

N = number of x,y pairs for a specific sampling period

T = number of sampling periods

t = index for sampling period

n = index for x,y pairs

Y = observed value

X = model-predicted value

2. Some caution must be exercised in interpreting the RI since it is affected by variability in observations as well as the degree of correspondence between observed and predicted values. It is a measure of the capability of the models only to the degree to which the observed data are considered "true." However, comparisons between simulations with a given model or between different models which result in a smaller RI for the same observed data would generally indicate an improvement. The RI was compared to other commonly used statistical tests by Wlosinski (1984) and was considered the best statistic for aggregating model results.

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* This discussion was taken from Martin (1986). All references cited in this Appendix are listed in the References at the end of the main text.

APPENDIX B: CALCULATED MONTHLY TEMPERATURE RELEASES FOR HOWARD A. HANSON RESERVOIR

Table B1

Calculated Monthly Temperature Release Characteristics

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
				1972			
Apr	5.83	1.36	9.30	3.50	5.78	2.81	0
May	8.40	2.06	13.40	5.50	8.88	-3.85	0
Jun	9.56	0.91	11.30	7.80	11.73	-3.64	0
Jul	13.42	1.47	15.70	10.40	13.55	-2.45	12
Aug	15.97	0.34	16.70	15.40	13.82	3.22	32
Sep	13.50	2.85	16.80	8.90	12.47	3.55	19
Oct	9.78	0.50	10.50	8.40	9.88	-1.76	0
Nov	7.13	1.06	8.70	4.50	6.77	1.65	0
Sum of squared deviations = 729.07							
				1979			
Apr	7.15	1.56	10.10	5.10	5.78	3.35	0
May	9.43	1.50	11.50	6.40	8.88	2.15	0
Jun	12.74	0.70	13.70	11.00	11.73	1.74	0
Jul	14.76	1.08	16.50	13.00	13.55	2.52	20
Aug	16.81	0.16	17.10	16.50	13.82	3.36	32
Sep	16.15	0.27	16.60	15.60	12.47	4.52	31
Oct	12.93	2.36	15.60	8.50	9.88	4.56	14
Nov	7.26	1.08	8.80	5.40	6.77	1.11	0
Sum of squared deviations = 1,223.28							

(Continued)

Note: Deviations are determined assuming natural stream temperatures using Equation 4 of the main text.

Table B1 (Concluded)

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
				1982			
Apr	7.15	1.65	12.00	4.40	5.78	5.65	0
May	8.45	1.46	11.90	6.70	8.88	-2.85	0
Jun	11.22	1.49	13.60	9.00	11.73	-1.82	0
Jul	14.14	0.51	15.00	13.30	13.55	1.06	10
Aug	15.66	0.49	16.40	14.90	13.82	3.01	32
Sep	14.90	1.12	16.60	13.50	12.47	3.57	19
Oct	11.51	1.56	13.80	7.90	9.88	2.56	0
Nov	5.78	1.31	8.30	3.60	6.77	-2.55	0
Sum of squared deviations = 520.54							
				1983			
Apr	8.37	1.86	11.50	5.10	5.78	5.15	0
May	9.58	1.27	11.80	7.40	8.88	1.93	0
Jun	12.77	0.42	13.40	11.80	11.73	1.52	0
Jul	13.68	0.54	14.60	12.30	13.55	-1.26	3
Aug	15.63	0.44	16.20	14.60	13.82	2.56	32
Sep	13.97	0.92	15.80	12.50	12.47	2.41	9
Oct	11.53	0.61	12.50	10.60	9.88	2.49	0
Nov	6.02	1.81	10.80	3.60	6.77	2.49	0
Sum of squared deviations = 371.77							

Table B2

Calculated Monthly Temperature Releases for Existing Outlet with Raised Pool

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
				1972			
Apr	5.05	0.32	5.80	4.30	5.78	-1.47	0
May	7.69	1.02	9.60	5.80	8.88	-1.85	0
Jun	10.52	0.43	11.30	9.60	11.73	-2.40	0
Jul	12.29	0.73	13.30	10.90	13.55	-1.95	0
Aug	14.43	0.63	15.40	13.30	13.82	2.01	18
Sep	13.72	2.16	15.70	10.00	12.47	2.81	20
Oct	10.91	0.63	11.80	9.30	9.88	1.76	0
Nov	7.71	1.18	9.40	5.30	6.77	1.40	0
Sum of squared deviations = 370.69							
				1979			
Apr	6.37	0.27	7.20	6.00	5.78	1.81	0
May	8.98	0.84	10.10	7.20	8.88	0.51	0
Jun	10.84	0.43	11.60	10.10	11.73	-1.26	0
Jul	12.64	0.61	13.70	11.60	13.55	-1.25	0
Aug	15.13	0.82	16.30	13.70	13.82	2.86	24
Sep	16.42	0.33	16.80	15.90	12.47	5.09	31
Oct	13.97	2.17	16.40	9.60	9.88	5.26	17
Nov	8.26	1.37	10.20	5.70	6.77	2.41	0
Sum of squared deviations = 1,238.93							

(Continued)

Note: Deviations are determined assuming natural stream temperatures using Equation 4 of main text.

Table B2 (Concluded)

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
1982							
Apr	5.45	0.47	6.10	4.40	5.78	-1.17	0
May	7.82	0.89	9.20	6.10	8.88	-1.25	0
Jun	10.31	0.62	11.30	9.20	11.73	-1.63	0
Jul	12.44	0.71	13.60	11.30	13.55	-1.61	0
Aug	14.56	0.58	15.50	13.60	13.82	2.11	20
Sep	14.94	0.67	16.00	13.80	12.47	3.31	22
Oct	12.27	1.44	14.30	8.90	9.88	3.36	0
Nov	6.33	1.59	9.40	4.50	6.77	-1.65	0
Sum of squared deviations = 581.58							
1983							
Apr	6.76	0.30	7.30	6.20	5.78	2.11	0
May	8.46	0.70	9.60	7.30	8.88	-0.84	0
Jun	10.55	0.59	11.70	9.60	11.73	-1.39	0
Jul	12.70	0.59	13.80	11.70	13.55	-1.46	0
Aug	14.62	0.50	15.40	13.80	13.82	2.01	21
Sep	14.30	0.62	15.40	13.30	12.47	2.44	10
Oct	12.34	0.71	13.60	11.30	9.88	2.99	0
Nov	6.65	1.92	11.30	4.20	6.77	3.09	0
Sum of squared deviations = 409.54							

Table B3

Calculated Monthly Temperature Releases for Single Wet Well

Outlet with Raised Pool

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
				1972			
Apr	5.73	0.66	7.20	4.40	5.78	-1.36	0
May	7.86	1.01	9.50	6.00	8.88	-1.50	0
Jun	10.95	0.69	12.60	9.50	11.73	-1.96	0
Jul	12.99	0.83	14.10	11.30	13.55	-1.82	0
Aug	14.27	0.72	15.40	12.70	13.82	1.71	17
Sep	12.70	1.18	15.10	11.00	12.47	-2.10	2
Oct	10.53	0.78	12.30	9.10	9.88	1.56	0
Nov	7.65	1.14	9.30	5.30	6.77	1.35	0
Sum of squared deviations = 189.54							
				1979			
Apr	6.48	0.46	7.70	6.00	5.78	1.81	0
May	9.21	0.77	10.50	7.70	8.88	0.81	0
Jun	11.85	0.63	12.80	10.10	11.73	0.46	0
Jul	14.02	0.82	15.50	12.80	13.55	1.52	12
Aug	14.69	1.29	16.10	11.90	13.82	2.71	21
Sep	14.13	2.25	16.10	9.60	12.47	4.44	20
Oct	13.63	2.13	15.90	9.50	9.88	5.06	16
Nov	8.30	1.37	10.30	5.80	6.77	2.51	0
Sum of squared deviations = 885.66							

(Continued)

Note: Deviations are determined assuming natural stream temperatures using Equation 4 of main text.

Table B3 (Concluded)

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
				1982			
Apr	5.85	0.86	7.60	4.50	5.78	0.45	0
May	8.04	0.94	9.70	6.30	8.88	-1.30	0
Jun	11.15	0.90	12.80	9.20	11.73	-1.89	0
Jul	13.51	0.66	14.60	12.30	13.55	0.62	3
Aug	14.29	0.92	15.40	12.00	13.82	-1.87	20
Sep	13.54	1.83	15.70	9.80	12.47	2.67	18
Oct	11.90	1.21	13.40	8.90	9.88	3.36	0
Nov	6.38	1.59	9.30	4.50	6.77	-1.65	0
Sum of squared deviations = 333.86							
				1983			
Apr	6.77	0.32	7.40	6.20	5.78	2.11	0
May	8.84	0.89	10.00	7.40	8.88	-0.44	0
Jun	11.54	1.13	13.00	10.00	11.73	-0.78	0
Jul	13.30	0.77	14.40	11.20	13.55	-2.36	1
Aug	14.40	0.59	15.20	13.10	13.82	1.81	20
Sep	13.25	0.87	15.20	11.30	12.47	2.04	2
Oct	12.22	0.65	13.40	11.10	9.88	3.09	0
Nov	6.66	1.95	11.40	4.10	6.77	3.19	0
Sum of squared deviations = 283.91							

Table B4

Calculated Monthly Temperature Releases for Single Wet Well Outlet and Sluiceway Blending with Raised Pool

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
1972							
Apr	5.74	0.60	6.80	4.30	5.78	-1.27	0
May	7.86	1.00	9.50	6.00	8.88	-1.50	0
Jun	10.91	0.60	12.00	9.50	11.73	-1.96	0
Jul	13.14	0.88	14.10	11.30	13.55	-1.82	0
Aug	13.94	0.17	14.10	13.60	13.82	0.21	0
Sep	13.06	1.47	14.60	9.30	12.47	-2.23	4
Oct	10.53	0.56	11.30	9.20	9.88	1.66	0
Nov	7.68	1.16	9.40	5.30	6.77	1.40	0
Sum of squared deviations = 162.02							
1979							
Apr	6.50	0.47	7.80	6.00	5.78	1.81	0
May	9.27	0.77	10.50	7.80	8.88	0.81	0
Jun	11.80	0.70	12.90	10.50	11.73	0.19	0
Jul	13.62	0.36	14.10	12.90	13.55	0.13	0
Aug	14.06	0.12	14.50	13.90	13.82	1.11	1
Sep	15.63	0.52	16.20	14.50	12.47	4.74	31
Oct	13.72	2.20	16.10	9.50	9.88	5.16	16
Nov	8.30	1.37	10.30	5.80	6.77	2.51	0
Sum of squared deviations = 886.99							

(Continued)

Note: Deviations are determined assuming natural stream temperatures using Equation 4 of main text.

Table B4 (Concluded)

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
1982							
Apr	5.88	0.84	7.30	4.40	5.78	0.33	0
May	8.30	0.76	9.70	7.20	8.88	-0.95	0
Jun	11.39	1.07	12.90	9.60	11.73	-1.22	0
Jul	13.64	0.32	14.10	12.90	13.55	0.61	0
Aug	13.90	0.17	14.10	13.50	13.82	0.23	0
Sep	13.50	0.39	14.30	13.00	12.47	2.44	0
Oct	11.98	1.28	13.60	8.90	9.88	3.36	0
Nov	6.30	1.57	9.30	4.50	6.77	-1.65	0
Sum of squared deviations = 234.49							
1983							
Apr	6.76	0.30	7.30	6.20	5.78	2.11	0
May	9.05	0.96	10.50	7.30	8.88	0.30	0
Jun	11.79	0.72	12.90	10.50	11.73	0.12	0
Jul	13.50	0.58	14.20	12.00	13.55	-1.56	0
Aug	13.93	0.18	14.10	13.60	13.82	0.21	0
Sep	13.62	0.33	14.10	12.90	12.47	2.09	0
Oct	12.19	0.64	13.30	11.00	9.88	3.09	0
Nov	6.65	1.94	11.40	4.20	6.77	3.19	0
Sum of squared deviations = 223.62							

Table B5

Calculated Monthly Temperature Releases for Dual Wet Well Outlet with Raised Pool Using Sine Curve as Temperature Objective

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
1972							
Apr	5.81	0.71	7.40	4.50	5.78	-1.26	0
May	7.78	0.93	10.20	6.70	8.88	-1.31	0
Jun	10.59	0.79	12.30	9.70	11.73	-1.86	0
Jul	12.34	0.64	14.40	11.90	13.55	-1.62	2
Aug	14.42	0.19	14.10	13.50	13.82	0.21	0
Sep	13.70	0.91	13.50	10.70	12.47	-1.24	0
Oct	10.95	0.63	11.30	8.90	9.88	1.16	0
Nov	7.56	1.09	9.10	5.30	6.77	1.35	0
Sum of squared deviations = 55.24							
1979							
Apr	6.07	0.49	7.30	5.30	5.78	1.31	0
May	9.04	0.92	10.60	7.30	8.88	0.73	0
Jun	10.80	0.72	12.90	10.50	11.73	0.20	0
Jul	12.63	0.36	14.10	12.80	13.55	0.13	0
Aug	15.14	0.16	14.10	13.60	13.82	0.31	0
Sep	16.40	0.48	13.70	12.00	12.47	2.04	0
Oct	14.12	1.73	14.90	9.20	9.88	4.55	12
Nov	8.26	1.32	10.00	5.70	6.77	2.21	0
Sum of squared deviations = 385.54							

(Continued)

Note: Deviations are determined assuming natural stream temperatures using Equation 4 of main text.

Table B5 (Concluded)

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
				1982			
Apr	5.87	0.82	7.30	4.50	5.78	0.24	0
May	7.87	1.05	11.10	6.80	8.88	0.85	0
Jun	10.36	0.90	13.70	9.60	11.73	1.31	0
Jul	12.43	0.30	14.00	12.90	13.55	0.33	0
Aug	14.69	0.18	14.10	13.50	13.82	-0.21	0
Sep	14.92	0.59	13.50	11.50	12.47	0.29	0
Oct	12.39	1.00	12.50	8.90	9.88	3.26	0
Nov	6.36	1.61	9.20	4.40	6.77	-1.75	0
Sum of squared deviations = 121.99							
				1983			
Apr	6.77	0.32	7.40	6.20	5.78	2.11	0
May	8.50	0.93	10.50	7.40	8.88	-0.15	0
Jun	10.60	0.72	12.90	10.50	11.73	0.13	0
Jul	12.72	0.42	14.00	12.40	13.55	-1.16	0
Aug	14.61	0.19	14.10	13.50	13.82	0.14	0
Sep	14.30	0.29	13.80	12.30	12.47	2.02	0
Oct	12.37	0.57	13.20	11.00	9.88	3.09	0
Nov	6.65	1.94	11.40	4.10	6.77	3.19	0
Sum of squared deviations = 190.81							

Table B6

Calculated Monthly Temperature Releases for Dual Wet Well Outlet with Raised Pool Using 14.4° C as Temperature Objective

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
1972							
Apr	6.26	0.66	7.70	5.10	14.40	1.91	0
May	8.13	1.05	10.20	6.40	14.40	-1.70	0
Jun	11.42	0.81	12.70	9.70	14.40	-1.96	0
Jul	13.93	0.78	14.60	11.80	14.40	-1.72	16
Aug	14.51	0.09	14.90	14.30	14.40	1.11	31
Sep	13.55	1.39	14.50	10.90	14.40	2.16	20
Oct	10.14	0.88	11.70	8.50	14.40	0.87	0
Nov	7.31	0.99	8.50	5.20	14.40	1.15	0
Sum of squared deviations = 142.18							
1979							
Apr	7.74	0.88	9.40	6.60	14.40	2.95	0
May	9.99	1.62	13.70	7.50	14.40	3.26	0
Jun	13.82	0.56	14.50	12.50	14.40	3.26	7
Jul	14.49	0.07	14.70	14.20	14.40	1.53	30
Aug	14.51	0.38	15.90	13.70	14.40	1.90	29
Sep	14.18	0.60	14.50	12.10	14.40	2.64	24
Oct	12.11	1.71	13.70	8.60	14.40	3.45	0
Nov	6.88	1.23	8.60	5.00	14.40	0.71	0
Sum of squared deviations = 543.13							

(Continued)

Note: Deviations are determined assuming natural stream temperatures using Equation 4 of main text.

Table B6 (Concluded)

Month	Temperature °C	Temperature Variance °C	Maximum Temperature °C	Minimum Temperature °C	Target Temperature °C	Maximum Temperature Deviation °C	No. of Days Temperature Exceeded 14.4° C
			1982				
Apr	7.55	1.30	10.00	5.90	14.40	3.45	0
May	8.68	0.98	10.90	7.20	14.40	-1.74	0
Jun	12.86	1.53	14.60	9.80	14.40	2.51	12
Jul	14.46	0.06	14.60	14.30	14.40	1.55	31
Aug	14.47	0.13	14.80	14.00	14.40	1.11	30
Sep	14.45	0.06	14.60	14.40	14.40	3.04	31
Oct	11.28	1.76	14.40	8.10	14.40	3.13	2
Nov	5.96	1.35	8.50	4.30	14.40	-1.75	0
Sum of squared deviations = 367.66							
			1983				
Apr	9.41	1.51	12.30	7.30	14.40	5.65	0
May	11.77	1.39	14.60	9.70	14.40	4.55	2
Jun	14.20	0.28	14.70	13.60	14.40	3.70	13
Jul	14.12	0.82	14.60	10.30	14.40	-3.26	23
Aug	14.51	0.12	15.10	14.40	14.40	1.25	32
Sep	13.99	0.52	14.50	12.90	14.40	2.36	12
Oct	11.00	0.97	12.90	9.40	14.40	1.78	0
Nov	6.19	1.38	9.40	4.10	14.40	-1.55	0
Sum of squared deviations = 712.22							

APPENDIX C: CALCULATED AVERAGE RELEASE TEMPERATURES FOR HOWARD A. HANSON RESERVOIR

Table C1

Calculated Average Release Temperatures

Plan	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
				1972				
A-72	5.83	8.40	9.56	13.42	15.97	13.50	9.78	7.13
B-72	5.05	7.69	10.52	12.29	14.43	13.72	10.91	7.71
C-72	5.73	7.86	10.95	12.99	14.27	12.70	10.53	7.65
D-72	5.74	7.86	10.91	13.14	13.94	13.06	10.53	7.68
E-72	5.81	8.28	11.39	13.64	13.92	12.40	10.25	7.56
F-72	6.26	8.13	11.42	13.93	14.51	13.55	10.14	7.31
				1979				
A-79	7.15	9.43	12.74	14.76	16.81	16.15	12.93	7.26
B-79	6.37	8.98	10.84	12.64	15.13	16.42	13.97	8.26
C-79	6.48	9.21	11.85	14.02	14.69	14.13	13.63	8.30
D-79	6.50	9.27	11.80	13.62	14.06	15.63	13.72	8.30
E-79	6.07	8.94	11.80	13.63	13.94	12.80	13.12	8.14
F-79	7.74	9.99	13.82	14.49	14.51	14.18	12.11	6.88
				1982				
A-82	7.15	8.45	11.22	14.14	15.66	14.90	11.51	5.78
B-82	5.45	7.82	10.31	12.44	14.56	14.94	12.27	6.33
C-82	5.85	8.04	11.15	13.51	14.29	13.54	11.90	6.38
D-82	5.88	8.30	11.39	13.64	13.90	13.50	11.98	6.30
E-82	5.87	8.57	11.96	13.63	13.89	12.62	11.49	6.36
F-82	7.55	8.68	12.86	14.46	14.47	14.45	11.28	5.96
				1983				
A-83	8.37	9.58	12.77	13.68	15.63	13.97	11.53	6.02
B-83	6.76	8.46	10.55	12.70	14.62	14.30	12.34	6.65
C-83	6.77	8.84	11.54	13.30	14.40	13.25	12.22	6.66
D-83	6.76	9.05	11.79	13.50	13.93	13.62	12.19	6.65
E-83	6.77	8.90	11.78	13.52	13.91	13.30	12.07	6.65
F-83	9.41	11.77	14.20	14.12	14.51	13.99	11.00	6.19

Note: Plan A = Calculated average release temperature for existing project
Plan B = Calculated average release temperature for existing structure with raised pool using the sine function as release temperature objective
Plan C = Calculated average release temperature for single wet well outlet with raised pool using the sine function as release temperature objective
Plan D = Calculated average release temperature for single wet well outlet and sluiceway blending with raised pool using the sine function as the release temperature objective
Plan E = Calculated average release temperature for dual wet well with raised pool using the sine function as the release temperature objective
Plan F = Calculated average release temperature for dual wet well with raised pool using 14.4° C as the release temperature objective